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Experimental Use of Aerial Photogrammetry to Assess the Long Term Responses of Bowhead Whales to Offshore Industrial Activities in the Canadian Beaufort Sea, 1984

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Northern Affairs Program

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ABSTRACT

This study tested a photogrammetric approach as a method to examine the effects of offshore industrial activities in the Canadian Beaufort Sea on bowhead whales. Vertical low-level aerial photography was used to measure and individually identify whales present adjacent to areas of industrial activity and in control areas remote from these activities. In addition, aerial surveys were used to estimate numbers of whales present in and adjacent to the areas photographed.

Specifically, the study attempted (1) to document daily and weekly movements of individually recognizable bowhead whales in relation to the presence or absence of industrial activities, (2) to determine whether individual whales return in subsequent years to areas where they encountered industrial activities, (3) to examine the relationship between a whale's length and its occurrence near industrial activities, (4) to determine whether bowheads in the industrial area are representative of the Western Arctic population, and (5) to increase the sample size of measured and individually recognizable whales.

This study answered these questions to varying degrees because the rate of inter-day resightings of individually recognizable whales was low, few whales were present and photographed within the industrial area itself, and few between-year sightings were recorded.

1. The within-year resighting rates in 1984 were significantly higher and the imputed rates of movement were lower in the control area (Franklin Bay) than in areas adjacent to industrial activities (Yukon coast and Mackenzie Delta area). Although the data are few, they suggest that whales in the area adjacent to industrial activities moved more rapidly than those in control areas. The cause of these rapid movements is unknown; these movements may have been related to changing food supplies or to industrial disturbance, or both.

2,3. Objectives 2 and 3 were not met directly by this 1984 study, but data collected in this study, in conjunction with those from other years, will be useful in addressing these points in future years.

4. The few whales in the industrial area in 1984 appeared to be representative of the Western Arctic population. Within the industrial area small whales were found in shallow nearshore areas and medium and large whales were found in offshore areas.

5. Length measurements were obtained for 391 different whales. We photographed 186 different whales that could be re-identified in future years.

The distribution of bowheads was uneven during the summer of 1984. Large numbers of whales were found in Franklin Bay, along the interface between the muddy Mackenzie Delta waters and clear offshore waters, and along the Yukon coast. Most of the Franklin Bay whales were either adults or large immature whales. In contrast, almost all interface and Yukon coast whales were immature. Few calves and few potentially breeding adult whales were photographed during 1984 studies.

SOMMAIRE

Cette étude a servi à mettre à l'essai une approche photogrammétrique devant permettre d'étudier les effets de l'activité industrielle sur la baleine boréale, dans la partie canadienne de la mer de Beaufort. Ainsi, grâce à des photographies aériennes prises à basse altitude à la verticale, on a identifié individuellement et mesuré les baleines trouvées près de la zone de travaux industriels ou encore dans l'une des aires témoins éloignées de cette zone d'activité. On a également fait des levés aériens qui ont permis d'évaluer le nombre de baleines dans les environs des aires photographiées.

Plus particulièrement, l'étude devant permettre (1) d'établir les déplacements quotidiens et hebdomadaires de différentes baleines boréales reconnaissables, par rapport à la présence ou à l'absence d'une activité industrielle, (2) d'établir si une baleine donnée qui a visité un secteur d'activité industrielle y retourne les années suivantes, (3) d'examiner le rapport pouvant exister entre la longueur de la baleine et sa présence près d'un lieu d'activité industrielle, (4) d'établir si les baleines boréales dans la zone industrielle sont typiques de celles que l'on trouve en général dans l'Artique de l'Ouest, et (5) d'accroître l'importance de l'échantillon de baleines mesurées et individuellement reconnaissables.

Dans les faits, l'étude a permis de répondre plus ou moins à ces questions : on a rarement observé une même baleine au cours de deux différentes journées, le nombre de baleines vues et photographiées dans la zone d'activité industrielle a été faible et peu nombreuses ont été les baleines vues durant chacunes des deux différentes années.

1. En 1984, les taux de détection du même cétacé au cours d'une même année étaient sensiblement plus élevés et les taux de déplacement imputés aux baleines étaient moins importants dans l'aire témoin (la baie Franklin) que dans les environs des zones industrielles (littoral du Yukon et du delta du Mackenzie). Les données, peu nombreuses, portent à croire que les baleines proches d'une zone industrielle se déplaçaient plus rapidement que celles dans l'aire témoin. Les causes en sont inconnues; peut-être s'agit-il de variations de la nourriture disponible ou du dérangement causé par les travaux industriels, ou des deux.

2 et 3. Les objectifs 2 et 3 n'ont pas été atteints dans le cadre de l'étude de 1984, mais les données recueillies, s'ajoutant à celles des autres années, permettront d'étudier ces dimensions à date ultérieure.

4. Les quelques baleines observées dans la zone industrielle en 1984 semblaient représentatives de celles que l'on trouve en général dans l'Arctique de l'Ouest. Dans la zone industrielle, on a relevé les petites baleines en eaux peu profondes, près du rivage, alors que les baleines grosses ou moyennes se trouvaient au large des côtes.

5. On a mesuré 391 baleines et photographié 186 d'entre elles, que l'on pourra reconnaître à l'avenir.

   La distribution des baleines boréales a été inégale pendant l'été de 1984. Elles étaient nombreuses dans la baie Franklin, près du delta du Mackenzie, là où ses eaux boueuses se mêlent aux eaux cristallines de la mer, et le long du littoral yukonnais. La plupart des baleines observées dans la baie Franklin étaient adultes ou immatures, mais de grande taille, alors que presque toutes celles vues là où se mêlent les eaux du Mackenzie et de la mer de Beaufort ou le long du littoral yukonnais étaient immatures. Peu nombreux ont été les baleineaux et les baleines en âge de se reproduire, photographiés en 1984.

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INTRODUCTION

The bowhead whale, Balaena mysticetus, is considered an endangered species in Canada, in the U.S.A., and internationally. Of the five historical groups, the 'Western Arctic' or 'Bering Sea' stock is the most numerous. The current best estimate of the size of this stock is slightly over 4000 animals. These whales winter in the Bering Sea between Alaska and the U.S.S.R., summer in the Canadian part of the Beaufort Sea and Amundsen Gulf, and migrate around western and northern Alaska in spring and autumn (Fig. 1, inset). This stock of whales is the object of a controversial hunt by Alaskan natives. As a result of this harvest, much effort has been directed toward counting the whales, studying their population biology, and analyzing the effects of the harvest on the population.

Industrial Activity and Bowheads

Recently, concern has developed about the possible effects of offshore oil exploration on bowheads. The area of intensive offshore oil exploration in the Canadian Beaufort Sea is in the middle of the summer range of the Western Arctic bowheads (Fig. 1). Exploration in the water depths frequented by bowheads has been underway since 1976. By 1983, this exploration involved five drillships, two active drilling caissons, six large dredges, ten twin-engined helicopters, five seismic exploration ships, four industry-owned icebreakers, eight supply ships, and numerous tugs, barges and other support vessels. Offshore oil exploration has also begun along the autumn migration route through the Alaskan Beaufort Sea, and exploration is planned along other parts of the migration routes in the Chukchi and northern Bering seas. The first sale of offshore oil leases in the winter range in the central Bering Sea took place in early 1984. Thus, Western Arctic bowheads may be exposed to oil industry activities in the future in all seasons and throughout much of their range.

Recent studies of bowhead whales in the Canadian Beaufort Sea have dealt with

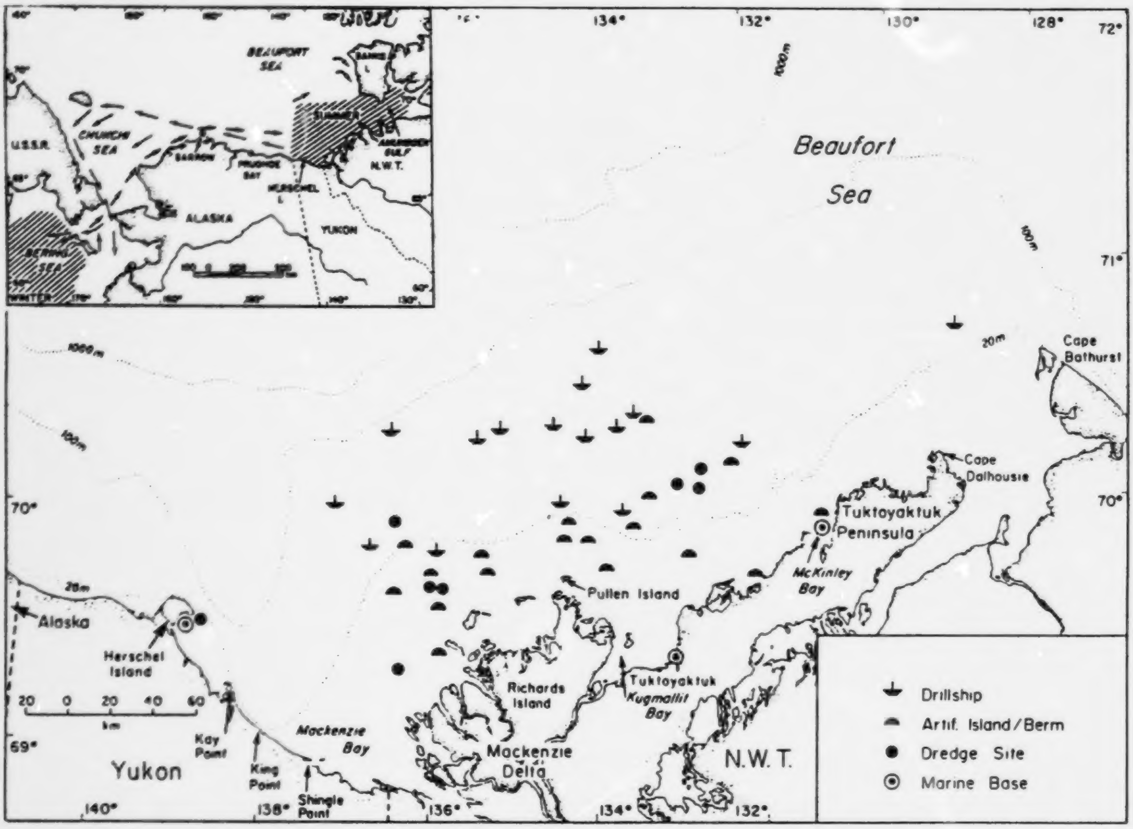

BEAUFORT SEA
BANKS I.
SUMMER
U.S.S.R.
CHUKCHI SEA
BARROW
PRUDHOE BAY
HERSCHEL I.
AMUNDSEN GULF
N.W.T.
ALASKA
YUKON
BERING SEA
WINTER
134°
132°
130°
128°
72°
71°
70°
69°
1000m
100m
20m
Beaufort Sea
Cape Bathurst
Cape Dalhousie
Tuktoyaktuk Peninsula
McKinley Bay
Pullen Island
Alaska
Herschel Island
20 0 20 40 60
km
Richards Island
Tuktoyaktuk
Kugmallit Bay
Kay Point
King Point
Shingle Point
Mackenzie Bay
Mackenzie Delta
Yukon
N.W.T.
140°
138°
136°
Drillship
Artif. Island/Berm
Dredge Site
Marine Base

FIG. 1. The eastern Beaufort Sea showing the main sites of offshore industrial activity in August and early September, 1980-84. **Inset:** Generalized pattern of seasonal movement of the Western Arctic population of bowhead whales. (Adapted from Richardson et al. 1985a.)

1. distribution, movements, and numbers (aerial surveys in 1980-84, funded by the oil industry directly or, in 1983-84, through the Environmental Studies Revolving Fund [ESRF]),
2. behavior and short-term reactions to industrial activities (behavioral observations and experiments in 1980-84, funded by the U.S. government--Minerals Management Service),
3. individual recognition and population parameters (photogrammetric studies in 1981-83, funded by the oil industry in 1981 and the U.S. National Marine Fisheries Service in 1982-83), and
4. energetic modelling and impact predictions through the Beaufort Environmental Monitoring Project (BEMP) funded by the federal departments of Indian Affairs and Northern Development (DIAND) and Environment (DOE).

The possibility that offshore oil exploration may affect bowheads was the primary reason for the studies of types 1, 2 and 4, above. The third type of study, involving photogrammetry, was conducted for other purposes (e.g., determination of length at maturity, population structure, population segregation by age and sex, etc.). In the present study, we apply these photogrammetric techniques to attempt to answer some of the main unresolved questions about industrial effects on bowheads.

Noise is one of the main reasons for concern about potential effects of industry on bowheads. Underwater sounds are believed to be very important to most marine mammals. Sound travels much farther than light in the water, and thus sound is the sensory modality most useful to marine mammals for acquiring environmental information and for communication between individuals. The hearing abilities of bowheads have not been studied, but this species produces a wide variety of calls, mostly at low frequencies and often at high intensity (Ljungblad et al. 1982; Clark and Johnson 1984). These calls apparently have communication functions (Würsig et al. 1982, 1985a). Detection of environmental sounds may also be important to bowheads, e.g. noise from ice and waves may be helpful in finding open water amidst areas of extensive ice.

Boat and aircraft traffic, icebreaking, dredging, drilling and especially seismic exploration all introduce low frequency noise into the water. Thus, industrial activity could lead to behavioral reactions ('disturbance'), masking of important natural sounds, stress, or displacement (Geraci and St. Aubin 1980; Acoust. Soc. Am. 1981; Richardson et al. 1983b).

Short and Long Term Effects

Behavioral studies in the Beaufort Sea have shown that bowheads sometimes react to approaching ships, aircraft, playbacks of recorded drilling and dredging noise, and operating seismic vessels (Fraker et al. 1982; Richardson et al. 1983c, 1984b, 1985b,c; Ljungblad et al. 1985b). The importance of these short term behavioral reactions is unknown. Industrial activities sometimes did displace whales for a kilometre or two. In these cases, feeding and social interactions gave way to travel, sometimes rapid, for a period of minutes or tens of minutes. It is not known whether such brief interruptions of normal activities have any lasting effects, or whether the individuals displaced a kilometre or two later returned to the locations where they encountered the disturbance. To resolve these questions, behavioral observations of recognizable individual whales would be needed over a period of days.

Bowheads sometimes have been seen for periods of several days in areas of the Canadian Beaufort Sea ensonified by dredge, drillship, or seismic noise (Fraker et al. 1982; Richardson et al. 1983c, 1984b, 1985b,c). It is possible that some bowheads habituate to the ongoing noise from continuous or repetitious industrial activities. However, it is not known whether the same individual bowheads remain in the ensonified area, or whether different whales are present on successive days. This is an important question. If some individual whales remain in ensonified areas for prolonged periods, one could conclude that they can adapt to those types of industrial activities. However, if individuals are present only briefly, and are replaced by other individuals, then the observations do not indicate that tolerance and habituation occur. To determine whether individual whales remain in ensonified areas, it is necessary to identify individual whales--a central part of this study.

Since 1980, when systematic aerial surveys of summering bowheads began, bowhead whales have become less numerous in the part of the Canadian Beaufort Sea where industrial activity is intense (Fig. 2). Bowheads were numerous there in 1980 (Renaud and Davis 1981), less so in 1981 (Davis et al. 1982), virtually absent in 1982 (Harwood and Ford 1983), and only slightly more common in 1983 than in 1982 (McLaren and Davis 1985). Whether this change is attributable at least in part to the increasing level of industrial activity is not known. If this trend is attributable to industrial activity, it could mean that industry has very important effects on the return of bowheads to their usual summer range. However, it is possible that natural factors such as the variable distributions of ice, freshwater influence, and food may also be involved. Bowheads were found in parts of the Canadian Beaufort Sea outside the main industrial area each summer from 1980-83 (Fig. 2). It is not known whether individual whales were more likely to return in subsequent years to non-industrial areas than to industrial areas; a multi-year study of recognizable individuals would be necessary to resolve that question.

In summary, short term reactions of bowheads to offshore industrial activities are amenable to experimental and observational study, but the medium and longer term effects of industrial activities on bowheads are more difficult to study. It is these longer term effects on geographic distribution and population size that are of most basic concern. Recent distributional results from the Canadian Beaufort Sea are consistent with the possibility that industrial activity causes displacement of bowheads from their traditional summer range. However, it is not proven that the observed trend is attributable to industry.

Because of the difficulties in studying such matters, there is little information about the long-term effects of human activities (aside from whaling) on any baleen whale species. Cases of geographic displacement as a result of disturbance have been suggested for gray, humpback, and some other whales, but the evidence ranges from weak to nil (Nishiwaki and Sasao 1977; Reeves 1977; Wolfson 1977; Norris and Reeves 1978; Mar. Mamm. Comm. 1979/80; reviewed by Richardson et al. 1983b). Whatever its cause, the decrease in

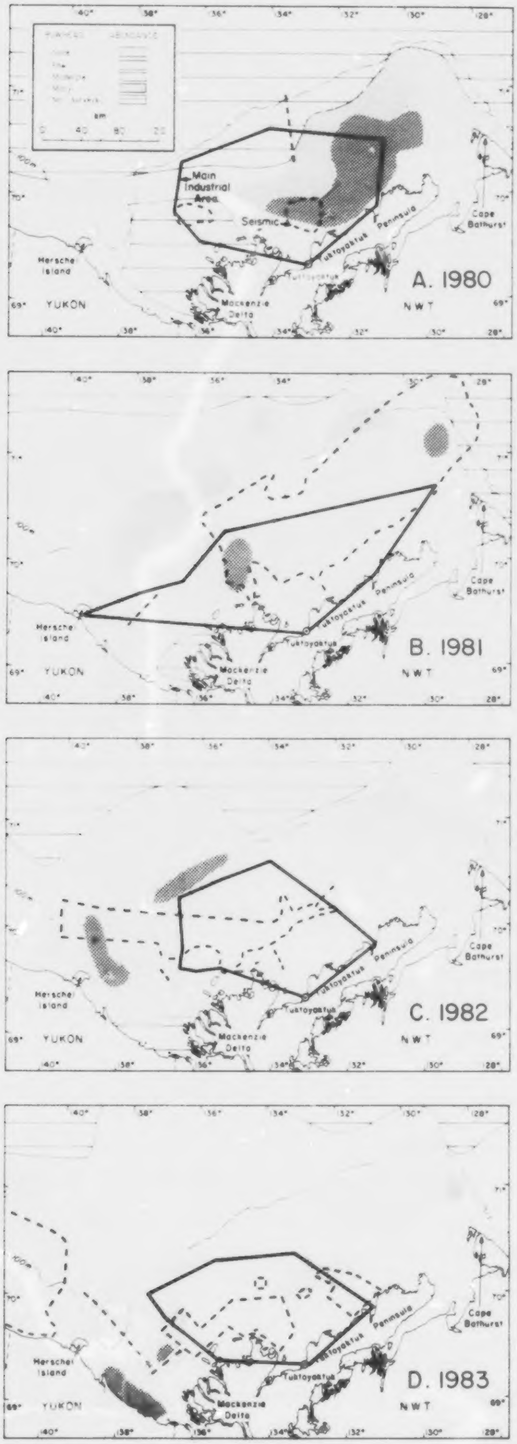

Main Industrial Area
Seismic
Herschel Island
YUKON
Mackenzie Delta
Tuktoyaktuk
Tuktoyaktuk Peninsula
Cape Bathurst
N W T
A. 1980
B. 1981
C. 1982
D. 1983
km
0 40 80 120
140°
138°
136°
134°
132°
130°
128°
70°
69°

FIG. 2. Generalized distribution of bowheads in late August of 1980, 1981, 1982 and 1983 in relation to the areas of industrial activity in mid and late August. The heavy solid line outlines the area of drilling, dredging and support activities. The heavy dashed lines show areas where seismic exploration took place. (Adapted from Richardson et al. 1984a.)

bowhead utilization of the industrial area in the Canadian Beaufort Sea is one of the best documented cases of year-to-year changes in baleen whale distribution.

General Approach

Our approach in the present study was to use the low-level aerial photographic techniques developed for life history studies of bowheads to address the question of the medium and longer term responses of bowheads to offshore industrial activity. Aerial photographs taken under controlled conditions can be used to determine the body lengths of individual bowheads in various parts of the study area in the Beaufort Sea. The length data can be used to infer the age and potential reproductive status of the photographed whales (Davis et al. 1982, 1983; Cubbage et al. 1984).

A substantial proportion of the bowhead population consists of animals with unique combinations of white pigmentation patterns on the lower jaw and in the fluke/caudal region, along with scars on the dorsal surface. When photographs of these well-marked animals are obtained in clear water and in relatively calm conditions, it is possible to identify many of the individual bowheads in an area. The ability to recognize individual animals and to determine their relative age (i.e. length) allows us to examine how individual whales, and various age classes of whales, react to industrial activities on a longer term basis. This approach requires repeated temporal coverage in each area through the season. It also requires sufficient geographic coverage to document segregation patterns and long distance movements, and to provide control areas that are unaffected by the industrial activities.

The study reported here is experimental in the sense that the photographic technique had not previously been applied to impact-related questions. As will be seen later, the results of the study were complicated by the lack of whales and repeated foggy and windy conditions in the industrial zone. Very large numbers of whales were present in waters along the Yukon coast and along the interface marking the western side of the Mackenzie River plume. However, these waters ranged from moderately to highly turbid and it was difficult to obtain high quality whale images in these areas. Nonetheless, useful results were obtained in spite of these complications.

Study Objectives

The general objectives addressed in the study are summarized here. The low-level aerial photographic method for identifying specific recognizable bowheads was used to document the occurrence and duration of stay of certain individuals near industrial sites and elsewhere in the Canadian Beaufort Sea. Emphasis was placed on repeated searches of industrial and adjacent areas to determine whether previously recognized bowheads were still present. We also compared resighting rates in areas with and without industrial activity. Resightings over periods of days were analyzed to assess whether whales exposed to industrial activity moved away faster than whales not so exposed. Resightings between years were also evaluated to indicate whether whales exposed to industrial activity in a given area show any reduced likelihood of returning to that area in subsequent years. To determine this, data from more than one year were needed. Some data on identifiable whales were obtained in 1981-83, so that some data on year to year recurrence rates could be derived in 1984. Finally, the aerial photographs allowed us to determine whether the whales near industrial activities were a random sample of the overall population. It also allowed assessment of whether some age and sex categories of whales were more likely than others to move away from industrial activities.

The specific objectives of the study can be formulated as a series of questions.

1. Do Individual Bowheads Remain near Industrial Sites for Prolonged Periods? Bowheads have sometimes been seen over periods of many days in areas ensonified by drillships, dredges, or seismic vessels. If the same whales were present throughout, then it can be concluded that they

show a certain degree of tolerance to industrial activities. However, bowheads travel frequently and widely during summer. It is possible that there was much turnover of individuals near the industrial sites, and that no one individual remained there for more than a few hours or at most a few days. If so, less tolerance of industrial activities has been demonstrated. The recurrence of bowheads near industrial sites can be evaluated by locating and identifying whales near ongoing industrial operations (e.g. dredge site, island construction operation, drillship), and then returning in subsequent days to search for whales and identify any that are found.

Resightings of whales near industrial sites would demonstrate tolerance of the industrial activity by at least a limited number of whales. Lack of resightings would be more difficult to interpret; the whales may have left because of the industrial activity or for some other reason. This uncertainty can be addressed by comparing the proportion of bowheads resighted in industrial areas and in 'control' non-industrial areas. This requires that the number of whales in the areas of concern be estimated during the first and subsequent searches.

A lower rate of recurrence in one industrial area than in one non-industrial (control) area might be due to chance or to unmeasured variables that are important to the whales (e.g. food supply). However, if recurrence rate were consistently lower in industrial areas, then the results would support the hypothesis that bowheads tend to leave industrial sites.

2. Do Individual Bowheads Return in Subsequent Years to Areas Where They Encountered Industrial Activity in a Previous Year? As noted above, numbers of bowheads in the main area of offshore oil exploration in the Canadian Beaufort Sea decreased markedly over the 1980 to 1983 period, even though bowheads continued to use other parts of the Canadian Beaufort. This may mean that bowheads tend not to return in later years to an area where they were previously exposed to industrial activities. However, the reduced utilization of the industrial area in

recent years may reflect some unknown reduction in food availability or a change in some other natural factor important to bowheads.

One way to begin to address this question is to determine whether recognizable bowheads tend to return to the same non-industrial areas in later years and, if so, whether the recurrence rate is similar or lower in industrial areas. Data from two or more years are obviously required in order to assess year to year recurrence rates. Few of the whales photographed in 1981-83 were in the main area of offshore industrial activity. Hence, it was unlikely that we would be able to determine whether any specific whales identified there in 1984 had been present in earlier years. Larger sample sizes were available from some other areas (e.g., Herschel Island) and it was theoretically possible to determine recurrence rates in these areas.

3. Do Whales of Different Age or Status React Differently to Industrial Activities? Most of the bowheads that are identifiable on vertical photographs are also measurable. Thus, it is possible to determine the size and, in some cases, the age, maturity and sex (females with calves) of the identified whale. If a sufficient number of whales were found and identified in the industrial area during the study, we could evaluate whether the tendency to remain in the area on subsequent days differed according to size or status of whale. This question is important since it provides an indication of what proportion of the bowhead population is actually exposed to offshore industrial activity in the Beaufort Sea.

4. Are Bowheads in the Industrial Area a Representative Sample of the Western Arctic Population? Only a small fraction of the Western Arctic population of bowheads occurred inside the main area of offshore oil exploration in the summers of 1982 and 1983. It is of interest to know whether these whales were representative of the population as a whole, according to age, sex, breeding status, etc. The 1981-83 photographic studies have shown that there is a considerable degree of segregation by age and perhaps sex. Mothers and calves were common some places and

absent elsewhere. In some areas, most whales were large mature animals, while in other areas most whales were small and immature. Thus, it is quite possible that the bowheads in the industrial area were not a representative sample of the population.

The 1982-83 photographic studies provided too few photographs of the few whales present in the main industrial area during those years to determine whether those whales were representative (Davis et al. 1983; Cubbage et al. 1984). If they were not representative, then one component of the population might be more tolerant of industrial activities. Such a result might also mean that one component of the population is especially dependent on the industrial area and potentially susceptible to any deleterious effects of the industrial activities. An objective of the photographic study reported here was to determine whether the whales in the industrial area were representative of the entire population.

5. Life History Data. An additional important objective of this study was to increase the sample size of measured and re-identified whales. These types of information are of critical importance in the long term process of understanding the basic biology and life history of the bowhead. Such basic parameters as calving interval, time of weaning, growth rates, reproductive rates, etc. remain unknown in this species.

This report is organized in a somewhat unusual manner because it is applying a novel, innovative approach to a series of impact-related questions. Because the aerial photographic technique has only been applied in large scale projects on two previous occasions (Davis et al. 1983; Cubbage et al. 1984), it is necessary to conduct full-scale technical analyses of the technique itself. These analyses are required to validate the technique and to examine potential biases. Once the technique has been validated, the photographic results can be used to address the specific objectives of the study. The technical analyses are presented in Appendices 1 to 3 rather than in the main body of the report where they would interfere with the clear presentation of the results relating to the principal study objectives.

METHODS

Industrial Activities

Detailed records of the various industrial activities in the Canadian Beaufort Sea during the summer of 1984 were obtained and tabulated by Richardson et al. (1985d). These data are summarized for the period 1 August-10 September 1984 in Fig. 3 (Ship Traffic), Fig. 4 (Helicopter Traffic), and Fig. 5 (Seismic Exploration). Details of industrial activities in previous years can be found in Richardson et al. (1983a, 1984a, 1985d). The data in Figs. 3, 4 and 5 define the zones of industrial activity against which patterns of whale distribution and behavior were assessed.

Study Area and Timing

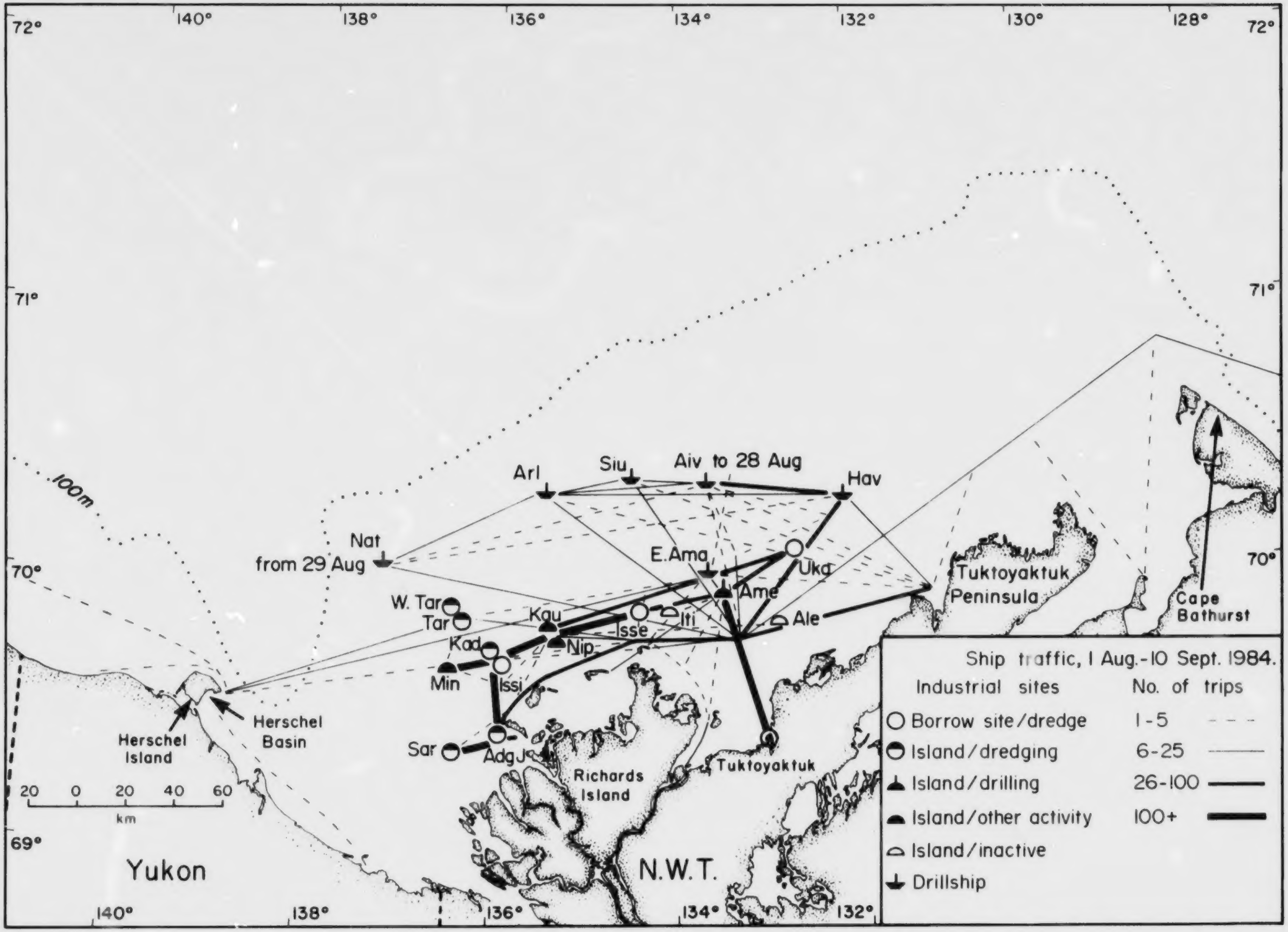
Field work was conducted from 14 August to 14 September, inclusive. Field work consisted of aerial surveys and searches, and low-level aerial photography. These activities were restricted, primarily to the seven survey blocks shown in Fig. 6. The reasons for selecting each of these blocks are discussed below.

Franklin Bay

Franklin Bay is an area where substantial numbers of bowhead whales are found each year. This area is remote from all sources of industrial activity and it was selected, therefore, as the prime 'control area'.

North and South Industrial Zones

These areas included the primary industrial activities of the oil industry during the summer of 1984. Industrial activities present in these areas during the 1 August-10 September period included the operation of four drillships, one drilling island, and dredging at three borrow sites. Traffic servicing these sites was very heavy and included both ship traffic (about 1250 passages) and helicopter traffic (about 1600 trips). Seismic activity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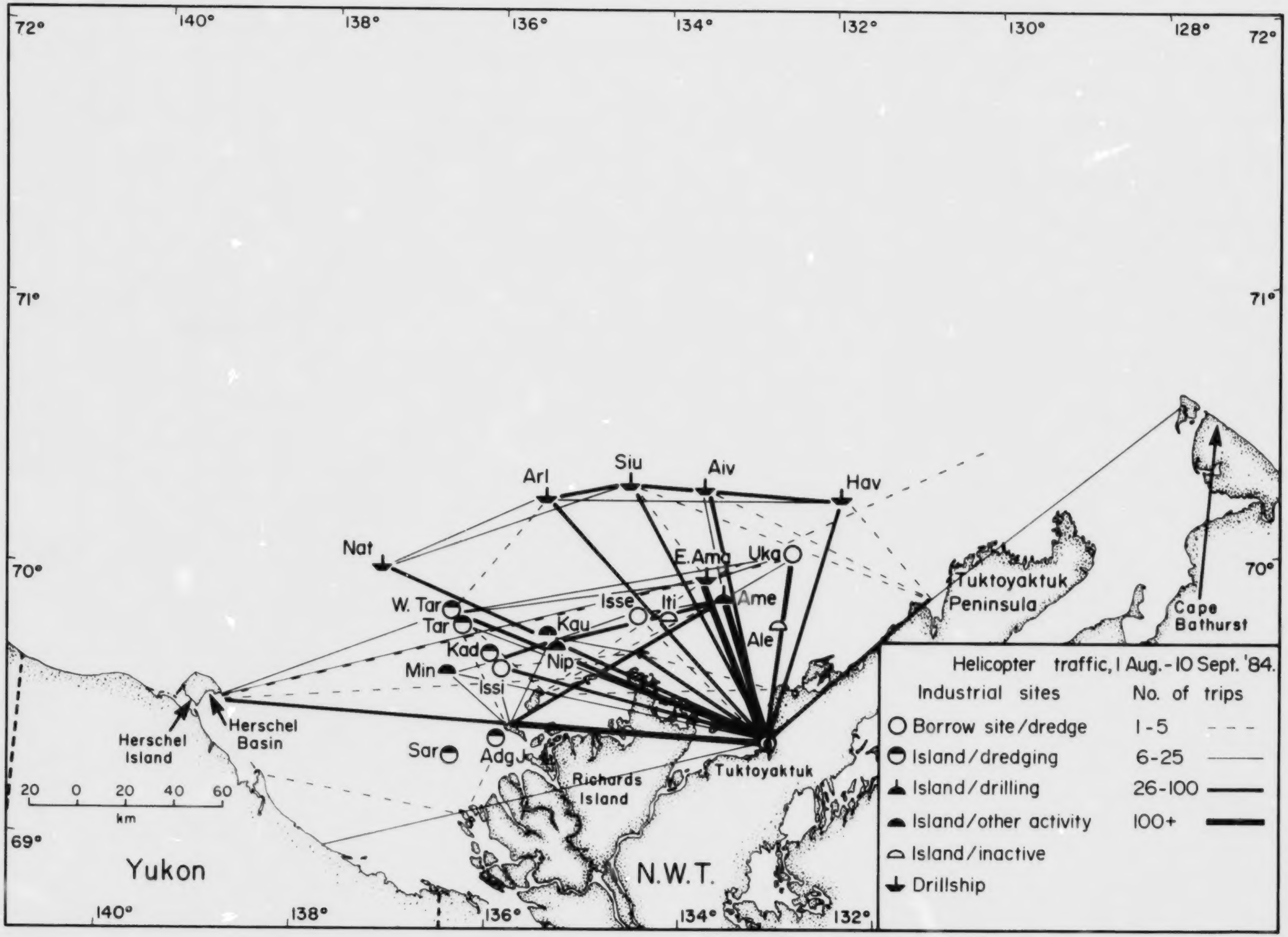
Ship traffic, 1 Aug.-10 Sept. 1984.
Industrial sites
No. of trips
○ Borrow site/dredge
Island/dredging
Island/drilling
Island/other activity
Island/inactive
Drillship
1-5
6-25
26-100
100+

FIG. 3. Ship traffic and industrial sites in the Canadian Beaufort Sea, 1 August-10 September 1984 (from Richardson et al. 1985d).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Kad
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Issi
Sar
Adg
Herschel Island
Herschel Basin
Richards Island
Tuktoyaktuk
Tuktoyaktuk Peninsula
Cape Bathurst
Yukon
N.W.T.
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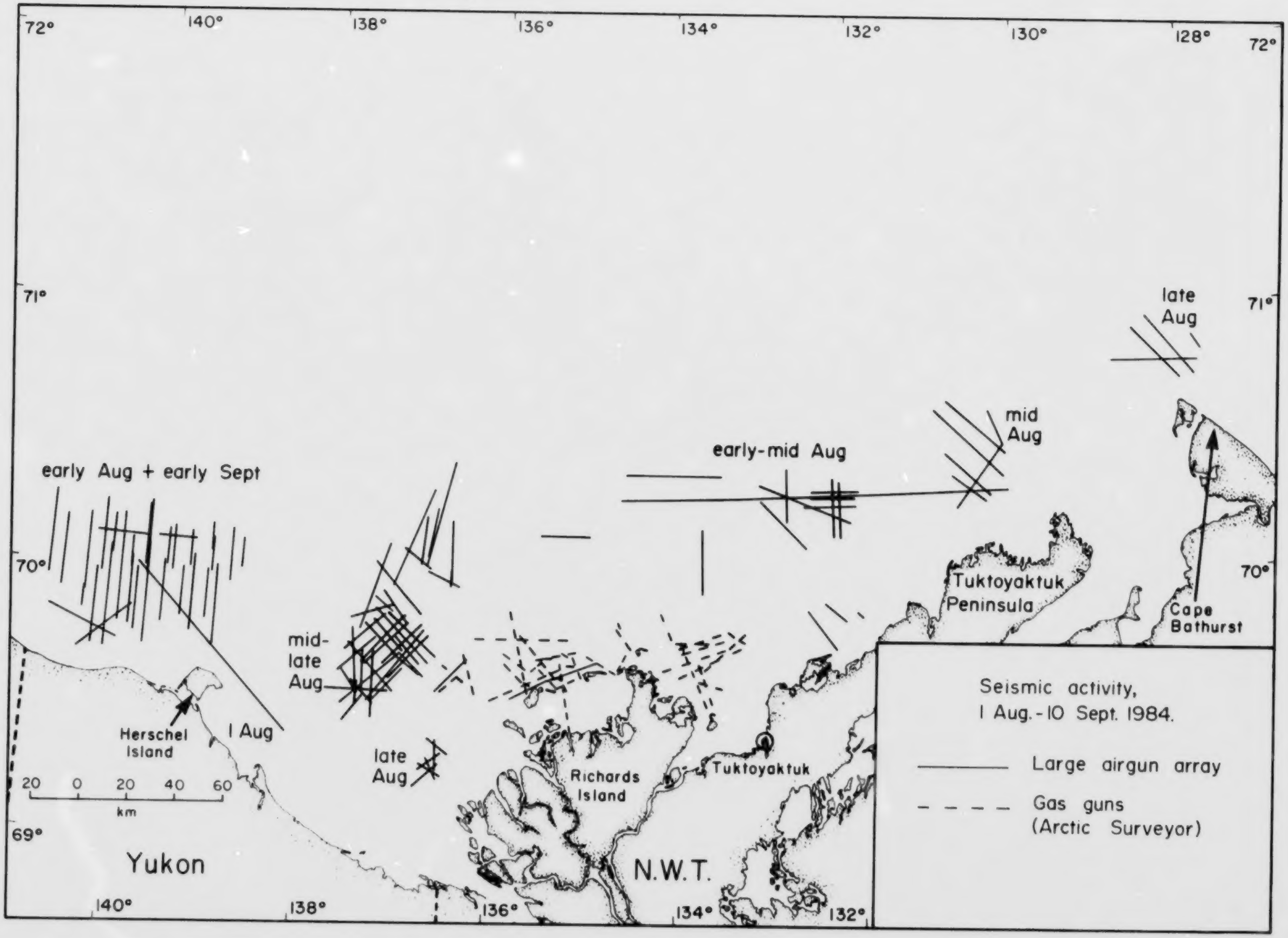
km
Helicopter traffic, 1 Aug.-10 Sept. '84.
Industrial sites
No. of trips
Borrow site/dredge
Island/dredging
Island/drilling
Island/other activity
Island/inactive
Drillship
1-5
6-25
26-100
100+

FIG. 4. Helicopter traffic and industrial sites in the Canadian Beaufort Sea, 1 August-10 September 1984 (from Richardson et al. 1985d).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Aug
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mid
Aug
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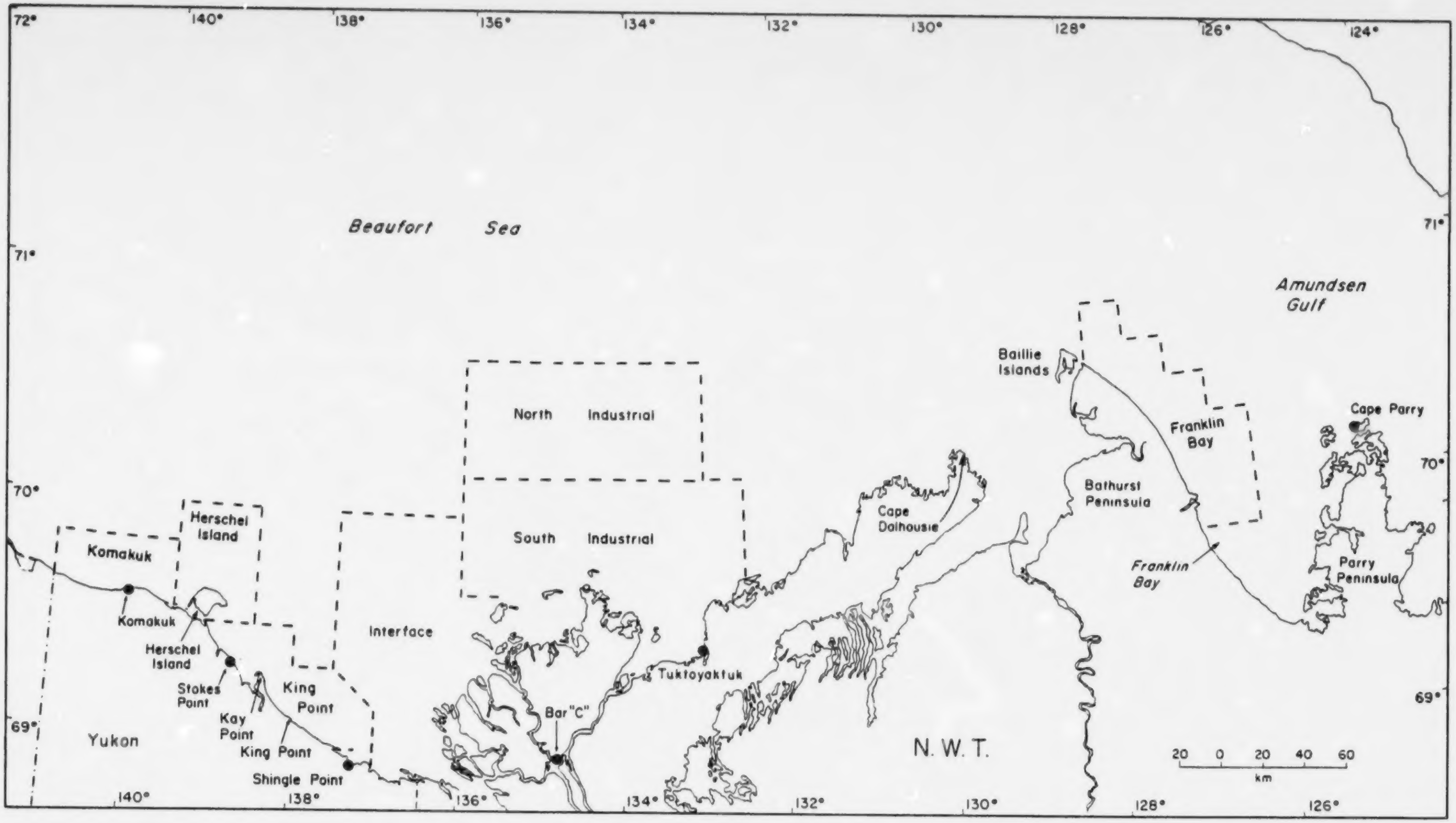
Aug
1 Aug
Herschel
Island
20 0 20 40 60
km
Yukon
Richards
Island
Tuktoyaktuk
N.W.T.
Tuktoyaktuk
Peninsula
Cape
Bathurst
Seismic activity,
1 Aug.-10 Sept. 1984.
Large airgun array
Gas guns
(Arctic Surveyor)
140°
138°
136°
134°
132°

FIG. 5. Seismic activity in the Canadian Beaufort Sea, 1 August-10 September 1984 (from Richardson et al. 1985d).


72°
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124°
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69°
Beaufort Sea
Amundsen Gulf
North Industrial
South Industrial
Interface
Herschel Island
Komakuk
Komakuk
Herschel Island
Stokes Point
Kay Point
King Point
King Point
Shingle Point
Yukon
Bar "C"
Tuktoyaktuk
Cape Dalhousie
N. W. T.
Baillie Islands
Bathurst Peninsula
Franklin Bay
Franklin Bay
Cape Parry
Parry Peninsula
20 0 20 40 60
km

FIG. 6. The study area in the southern Beaufort Sea showing the locations of seven survey blocks that were sampled.

included use of a large airgun array in the North Industrial Zone in early August, and both large airgun arrays and gas guns in the South Industrial Zone.

Interface Zone

This area contains a major portion of the interface between the relatively clear offshore waters and the highly turbid, muddy water of the Mackenzie River plume. The location of this feature varied daily due to the influence of weather (i.e. wind) and oceanographic factors. Feeding whales were frequently located along this feature. Whale sightings here were considered separately from other nearby sightings because of a possible association of whales with the interface. Industrial activities in this area included dredging associated with five island sites in and adjacent to the northeast corner of this zone. A drillship was positioned less than 10 km north of the northern boundary of this zone beginning on 29 August. Traffic servicing these sites was substantial with about 560 trips by ships and about 520 helicopter trips during the 1 August-10 September period (Figs. 3 and 4). Seismic exploration was extensive and included the operation of large airgun arrays and gas gun arrays (Fig. 5).

King Point Zone

This zone along the Yukon coast was selected because hundreds of bowheads were present in this area in August 1983 (McLaren and Davis 1985). Similarly, substantial numbers were present when we first surveyed this area on 15 August 1984. Industrial activity in the King Point Zone was very light. Seismic noise was rarely detectable near whales in that area (Richardson et al. 1985b), and there were fewer than five ship passages and 12 helicopter overflights (Figs. 3 and 4). Industrial noises were introduced into the water in the King Point Zone as part of a series of experiments on the short-term responses of bowheads to industrial sounds (Richardson et al. 1985b).

Herschel Island Zone

The marine base operated by Gulf Canada Resources Inc. was located in and near Pauline Cove off southeast Herschel Island. The base consisted of a moored supertanker (Gulf Beaufort), accommodation barge, and a variety of other vessels. Ship traffic was between 25 and 35 passages, and helicopter flights numbered about 110 within the 1 August-10 September 1984 period. There was seismic exploration north of Herschel Island in early August and early September.

The northern coast of Herschel Island and the offshore waters over the deep Herschel canyon were heavily used by bowheads in 1982 when large numbers of photographs were obtained (Davis et al. 1983). The area was selected for study in 1984 in the hope that inter-year recurrence rates could be determined for 1982 vs. 1984.

Komakuk Zone

The nearshore waters along the western Yukon coast were selected as a control area. Industrial activity in this zone consisted of some seismic exploration but fewer than five ship passages; there were no documented flights by oil industry helicopters (Figs. 3-5). In addition, bowheads have often occurred in this zone in previous years and the zone is bathymetrically more similar to the industrial zones than is the Franklin Bay control area.

Survey Aircraft

Aerial surveys and photography were conducted from a deHavilland Series 300 Twin Otter operated by Kenn Borek Air and based at Inuvik, N.W.T. The aircraft was equipped with a Collins LRN-70 VLF navigation system for accurate offshore navigation along transect lines during surveys and for determining the positions of whales during photography sessions. The aircraft was equipped with a radar altimeter for accurate maintenance of survey altitudes and for determining the aircraft's altitude at the time each photograph was taken. An intercom system provided for communication among the pilot and all scientific personnel.

One surveyor occupied the co-pilot's seat during all aerial surveys and photography sessions. The window used by this observer was standard equipment. The surveyor occupying the rear-most left seat observed through a specially fitted bubble window that afforded much greater forward and downward visibility than does a standard Twin Otter window.

Aerial Survey Procedures

Aerial surveys were flown at an altitude of 152 m (500 ft) and a ground speed of 200 km/h (110 kts). Transect width was 2 km; this consisted of two 1000 m wide strips extending from 100-1100 m on each side of the aircraft. However, all whales sighted were recorded regardless of distance from the aircraft. Transect width was chosen on the basis of the sightability tests done by Davis et al. (1982). Surveys were conducted by two 'prime' observers who occupied the co-pilot's seat on the right side of the aircraft and the rear-most seat on the left side of the aircraft. The observations of these two surveyors were supplemented by those of the photographer who occupied a right seat at the rear of the aircraft during most flights and a left seat (two behind the pilot) occasionally. Data presented in this report are based on observations of all observers present during a given flight except that density information is based on sightings on the transect strip by the two 'prime' observers.

Surveyors recorded all observations onto audio tapes. Information for each sighting included number, presence or absence of calves, and lateral distance of the animal from the aircraft path. Whenever practical, an inclinometer (Suunto PM-S/360S) was used to determine the angle of depression of the line to the animal when the whale was directly to the side of the aircraft. Lateral distances of bowheads from the centre of the transect were later calculated using the sighting angle and aircraft altitude. This ensured that on- and off-transect bowheads were accurately distinguished.

During systematic surveys the position along the transect route was interpolated by use of an interval timer system, digital watches, and the aircraft's navigation system. The timer produced a sound audible to all observers at 2-min intervals. This division of transects into 2-min transect segments permitted the mapping of habitat conditions and bowheads observed during surveys. More details of the survey procedures are provided in Davis et al. (1982).

Aerial Search Procedures

When whales were encountered or when we returned to an area where whales were photographed previously, systematic surveys were interrupted and intensive searches were conducted in and around the area. These searches differed from transect surveys in that the aircraft remained over an area for a prolonged period of time, the exact co-ordinates of all sightings were recorded, and the number of whales in each area could be estimated. If no whales were sighted during an intensive search, we were confident that few if any whales were present.

When whales were encountered during a systematic survey, we recorded the position of the original sighting and flew circles that passed near the original sighting and extended as far as 5 km from the sighting. If additional whales were sighted, the area that was being circled was extended to include these whales. The number of whales in the area was estimated and we attempted to photograph each surfaced whale that we sighted until we thought that we had photographed most of the whales at least once.

When we were returning to an area where we had previously obtained photographs, either a "spiraling search pattern" or a "moving ellipse search pattern" was used. The "spiraling search pattern" consisted of returning to the location where we originally photographed the whales and flying circles of gradually increasing radii until the aircraft was about 15 km from the centre point. If whales were encountered the search pattern was interrupted and the above-described photographic procedure was initiated.

The "moving ellipse pattern" was used to search large areas that had been photographed previously. Large overlapping circular or elliptical patterns with radii up to 15 km were flown along coastlines or between longitude lines. Each ellipse overlapped previous ellipses so that several passes were made over and near each area of the sea surface. If whales were not sighted during this type of search pattern, it is unlikely that any were present. When whales were encountered we circled over them, as described above, and then resumed the "moving ellipse pattern".

During all of these above-described searches, the positions of all whales and survey lines were recorded on field maps as well as onto audio tapes so that information on locations of whales was readily available for future use while conducting field studies.

Photographic Procedures

During aerial photography sessions, a navigator/spotter was present in the right front seat (co-pilot's seat) and a recorder/spotter was present in the left rear seat adjacent to the camera port. The navigator and recorder spotted the whales to be photographed and estimated the numbers of whales present in each photographic sampling area. The photographer was seated adjacent to the camera port and faced the rear of the aircraft so that he could brace himself and look vertically down the camera port. The camera was hand held. When a whale was sighted, the pilot attempted to fly the aircraft directly over the whale while it was still on the surface. The pilot maintained the aircraft at a constant altitude and in a level attitude while above the whale so that the camera could be held steady and perpendicular to the water surface. Where possible, changes in aircraft power settings and sharp turns were avoided during approaches to the whale. Whales appeared to react more readily to overflights when sharp turns or changes in power settings were made as we approached.

We attempted to sight whales ahead of the aircraft and fly directly over them. The navigator warned the photographer of the approach of a whale. When the whale was obscured from view by the nose of the aircraft, the photographer was alerted to be prepared to photograph the whale. Approximately 5-8 seconds later, when the aircraft was directly over the whale, the navigator recorded the time and position and the pilot noted the altitude to the nearest 1.5 m (5 ft) from the radar altimeter. The pilot then relayed the altitude to the navigator and the recorder over the intercom system. If a whale was photographed, the recorder, who was adjacent to the photographer, recorded the roll and frame number, date, time, shutter speed, lens aperture, altitude, whether the photograph was vertical or oblique (as judged by the photographer), the estimated number of whales in the photograph, and any other relevant comments.

It was essential to have an accurate record of the altitude in order to determine true lengths of whales from the measurements taken from the photographs. In order to reduce errors due to incorrect recording of altitude, both the navigator and the recorder recorded the altitude of each photograph. The altitudes recorded by both observers were later compared to verify that a recording error had not been made. To prevent rolls of film from being mixed during handling or processing, each roll was labelled externally and also contained a photograph of a sheet of paper indicating the roll number and date.

Hand holding the camera instead of having it rigidly mounted permitted us to take oblique photographs when the whale was slightly to the side or when whales were observed by the photographer as the aircraft was turning to make an approach toward other whales. Small errors in estimating actual sizes of whales are expected because the camera was hand held and may not have been vertical when the photograph was taken. However, this potential for error was also present in the photographs taken for calibration, and measurements from the calibration photographs indicated that these errors were usually small and did not vary substantially from photograph to photograph (see Appendix 1--Measurements of Known Length Targets). Hand holding the camera also permitted us to take vertical photographs even when sharp maneuvering was necessary to position the aircraft over the whale.

Photographic Equipment

Photographs were taken through optical glass in a 49 cm (19.5 in) diameter camera port in the floor of the Twin Otter using a hand held Pentax 6 x 7 cm camera equipped with a pentaprism viewfinder and a 105 mm f2.4 SMC Takumar lens. Two identical cameras and lenses were used. Cameras were alternated between rolls of film until 11 September when one camera malfunctioned; thereafter, only one camera was used. Regular alternation of the cameras reduced any potential biases that might have been associated with one of the cameras. Analyses of data collected in 1982 using the same two cameras indicated that no significant differences existed among measurements obtained using the two cameras. Reflected light was measured using a hand held Sekonic model L-398 light meter to determine the proper exposure for photographs that would permit a shutter speed of 1/500 or 1/1000 sec. Ektachrome 200 color reversal film was used during all photography; this results in positive 6 x 7 cm transparencies, from which prints can be made.

Calibration Techniques

In order to determine if there were systematic biases in our photographic techniques, and to assess the repeatability of measurements from the photographs, we took a series of photographs of a specially designed calibration target on four separate occasions during the study period. The standard photographic methods were used to estimate the dimensions of the target, which were already known. Comparison of the estimated and actual lengths provided a check on the accuracy of the estimates, and a way to derive correction factors for any consistent biases. The techniques used were identical to those used during photography of the whales and to those used in 1982 (Davis et al. 1983).

The target was constructed of roofing (tar-impregnated) paper onto which calibration marks were painted. Intervals of 1.00, 3.00, 4.00, 7.00, 10.00, 15.00 and 20.00 m were measured (Plate 1). The spacing of lines was verified on each occasion using a metal tape-measure. The target was carried in the aircraft and was set up at the time of the calibration flight. The target was placed on a flat area on an abandoned or infrequently used runway located at or near sea-level.

The analyses of the calibration data are presented in Appendix 1. The validity of the measurements is verified in Appendix 2.

Measurement Techniques

Whale and calibration images were measured directly from the developed films with the aid of a Zeiss binocular dissecting microscope (16 or 32X magnification) and a Wild stage micrometer. Actual measurements from the film were recorded to 0.01 mm. To reduce measurement error, the average of three blind replicate measurements was used as the true measurement. If the difference between the two higher or two lower individual measurements was more than 1% (or in the case of measurements smaller than 3.00 mm, if the difference exceeded 0.03 mm), two additional measurements were taken. The highest and the lowest of the five measurements were rejected and the remaining three measurements were averaged. Differences of more than 1% among measurements on good quality photographs were few and probably resulted from errors in reading or recording measurements. On poor quality photographs such differences were common. Differences in measurements that are due to the quality of the imagery are discussed in Appendix 2, where repeat measurements of individual whales are discussed.

We attempted to make three different measurements from each whale photographed. They were the total length of the whale, the snout-to-blowhole distance, and the width of the tail fluke. The last two measurements were taken because, during previous studies, a strong relationship was found to exist between these measurements and the total length of the whale. By establishing this relationship, the lengths of some additional whales could be determined from photographs where good quality measurements of only snout-to-blowhole distance or fluke width were obtained.

Length

The length of each whale was measured from the tip of the snout to the notch in the fluke. For whales that were twisted, lengths were calculated by making two or more measurements along the mid-dorsal line as shown on Plate 2.

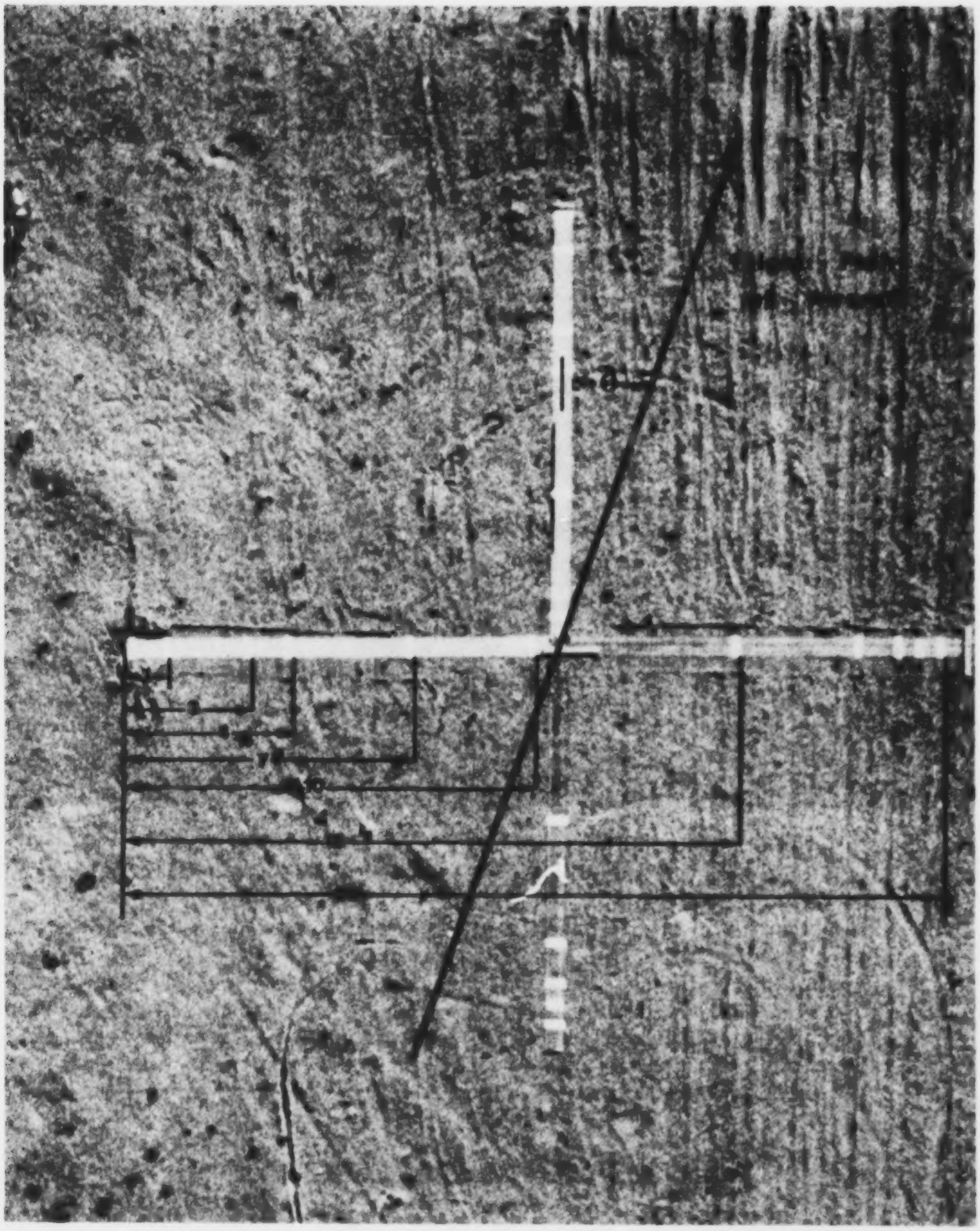

PLATE 1. The aerial survey target indicating the measurements (m) that were taken.

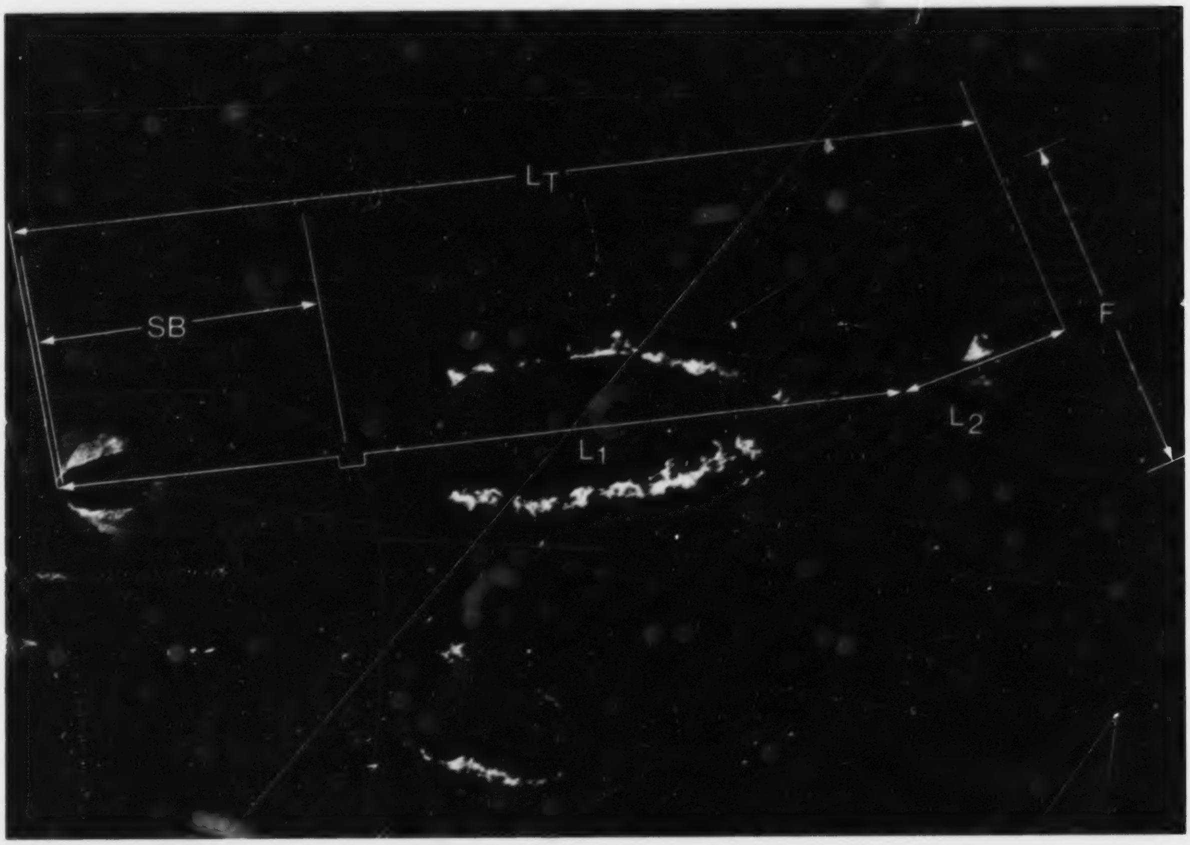

PLATE 2. A photograph of bowhead 81-06-09#5 showing the measurements that were taken from the film. The total length (L_T) was obtained from two measurements along the mid-dorsal line (L_1 and L_2). The snout-to-blowhole measurement (SB) is grade 1 but the fluke width (F) measurement is grade 4 because the distal portions of the fluke are slightly downturned (see text for further explanation).

Snout-to-Blowhole Distance

The snout-to-blowhole distance was measured from the tip of the snout to the longitudinal center of the two blowholes (Plate 2). Only horizontal whales whose snout and blowholes were both visible were considered measurement grades 1 and 2 (for description of measurement grades see below). This distance is a horizontal projection of the snout-to-blowhole measurement taken from dead whales.

Fluke Width

The maximum width of the flukes was measured (Plate 2). Only flukes that were horizontal, flat and clearly visible were considered for grade 1 and 2 measurements. The fluke width measurement from the whale in Plate 2 is grade 4 because the distal portions of the flukes are down-turned. If the flukes were flat, the trailing edges would form an approximately straight line.

Calculation of Object Sizes

The lengths of the whales, the snout-to-blowhole distances, the fluke widths and the dimensions of the calibration target were calculated using the following formula (Jacobson 1978):

$$\text{object size} = \frac{\text{altitude x image size}}{\text{focal length of lens}}.$$

The correction factors derived in Appendix 1 were then applied to the measurements to determine true object size.

Evaluation of Measurement Quality

The photographs obtained during this study varied from excellent through marginally acceptable to unacceptable due to widely varying environmental conditions. In addition, even under the best conditions for photography, the quality of the image of the whale varied because of its position relative to the water surface, its posture, its activity, and the turbidity of the water. In order to better evaluate measurements obtained and to differentiate between measurements from a good image and those from a poor image, a series of seven categories (grades) was defined. The different grades do not have clearly defined boundaries and the assignment of a measurement to a particular grade is somewhat subjective. Nevertheless, measurements evaluated as the same grade are of similar quality. Where doubt existed as to the grade of a particular measurement, it was assigned to the higher numbered grade. To improve consistency, all grades were assigned by only one of us (WRK) who also assigned the grades during our study in 1982 (Davis et al. 1983).

The seven grades and the criteria for including the measurement in each grade are as follows:

Grade 1 - The whale was flat, horizontal, straight, or almost straight, and the extremities measured were distinct.

Grade 2 - The whale was approximately flat and horizontal but may have been twisted slightly.

Grade 3 - The whale was slightly inclined, arched or flexed or severely twisted with distinct extremities, or it was approximately flat and horizontal or slightly twisted with indistinct extremities.

Grade 4 - The whale was arched or flexed or severely twisted and the extremities measured could be indistinct.

Grade 5 - The uncorrected measurement taken was known to underestimate the actual measurement because the whale was severely arched, flexed, or inclined. Grade 5 measurements that are used in the report are multiplied by 1.0185 to make them comparable to grade 1-4 measurements (see Appendix 1--measurements of reidentified whales).

Grade 6 - One of the extremities of the whale was not visible but some feature was visible which permitted an estimate of the length of the whale.

Grade 7 - The measurement taken was known to seriously underestimate the actual measurement because the photograph was oblique or the whale was more than one of the following: arched, flexed, tail up or down, inclined or severely twisted. These measurements are not used in this report.

The grades 1-4 that are described above are identical to those of Davis et al. (1983). The grade 5 measurements of Davis et al. (1983) were subdivided into grades 5 and 7 based on the criteria described above. The grade 6 measurements were from images that would not have been measured by Davis et al. (1983) but were measured during this study because of the high proportion of whales that were photographed in muddy water where the snout or flukes could not be seen clearly.

Photo-Identification

Whale images were enlarged to a standard length (about 10 cm) and custom processed as 5 x 7" color prints. We used prints in our photo-identification studies because they are easy to handle and it is possible to examine and conduct detailed comparisons of several photographs at once. We used a key (Davis et al. 1983) that enabled us to compare each print to four selected standards exhibiting varying amounts of white coloration on the lower jaw and on the fluke/caudal region. Prints were assigned to one of four categories according to the amount of white on the lower jaw, and one of three categories according to the amount of white in the fluke/caudal region. Thus, prints were assigned to one of 12 (4x3) files based on a combination of lower jaw and fluke/caudal region characters. An additional eight files were established for photographs in which the lower jaw, fluke/caudal region, or both lower jaw and fluke/caudal characters could not be determined. The key we used to create these files was reviewed and tested at a workshop held at the National Marine Mammal Laboratory in Seattle (Braham and Rugh 1983).

Each print in a given file was carefully compared with all other prints in that file, and in adjacent files, to determine whether any other photographs of that whale were present in the collection. Using this approach, one of us (GWM) working without access to length measurements found that we had more than one photograph of 123 different bowheads. Another 13 bowheads were re-identified later, bringing the total number of individual whales represented in more than one photograph to 136. These latter re-identifications were based on a combination of criteria, including markings, length measurements, and what might be considered circumstantial evidence. For example, when consecutive poor quality photographs contained individuals with nearly identical lengths, these photographs were subjected to special scrutiny. Several re-identifications resulted from such efforts. Re-identifications of this type are useful in that they allowed us to exclude duplicate length measurements from our length-frequency distributions, but whales identified in this manner probably would not be recognized if they were re-photographed on other days.

Some explanation should be made here of the varying sample sizes used throughout the following text when discussing repeat measurements, re-identifications and duplicate photographs. When comparing repeat measurements of re-identified whales, only those 123 re-identifications that were made without access to the length data have been considered. Length measurements (grades 1-6) were available for 110 of the 136 re-identified whales and at least two length measurements exist for 70 of those 110.

All but one of the 123 whales that were originally re-identified (without access to length measurements) were included in the photo-identification files. (Two grade C images of the same whale, i.e. images of a whale originally considered unlikely to be recognized if rephotographed, were not included in the photo-identification files, but were later recognized as duplicate photographs of the same whale.) Seventy-two of the 122 whales were 'fully classified' whales (i.e. both snout and tail visible) and the remaining 50 were 'partially classified' whales.

Eleven of the 13 whales that were subsequently re-identified (based on a variety of criteria) were included in files 1-12. The remaining two whales were included in files 13-20. Thus, when discussing numbers of re-identified whales in the photo-identification files the sample sizes are 83 for files 1-12 and 135 for files 1-20.

In total 61.0% (83 of 136) of the whales that we photographed more than once were included in files 1-12 (fully classified). This percentage is considerably lower than in 1982 when 85.1% (63 of 74) of the re-identified whales were in files 1-12. This difference is almost certainly attributable to increased photographic effort in areas of turbid water in 1984, which resulted in an increased number of photographs in which snout and fluke/caudal characters were obscured and could not be classified.

Re-identification Grades

Each printed whale image was assigned a re-identification grade according to Davis et al. (1983). Photographs of whales that we believed would be recognizable in a photograph of similar or better quality taken in another year were given a grade of A. Photographs of whales that would be recognizable in a photograph of similar or better quality taken the same day or within a few days of the date of the original photograph were given a grade of B. Photographs of whales that we considered would not be recognizable in a photograph of similar or better quality taken on the same or any other day were given a grade of C. The grading of prints involved a number of subjective assessments of the quality of the photograph (including consideration of focus, resolution, lighting, glare, reflection, sea state, water turbidity, and the position of the whale) and the distinctiveness of the whale. A poor quality photograph of a very distinctively marked whale might be graded A while an excellent photograph of a whale with no distinctive markings might be graded C. Whales given a grade of B were often well marked with features such as mottled patterns that we believe to be temporary.

RESULTS

Analyses of Photographic Techniques

The results of the present study depend entirely upon the validity of measurements and whale identifications obtained from the aerial photographs. The technique is still novel and has only been applied to bowheads in three previous studies (Davis et al. 1982, 1983; Cubbage et al. 1984). The results of the detailed analyses of the photographic techniques are presented in Appendices 1 to 3. The appendices clearly document that the measurements obtained from photographs of bowhead whales are both reliable and repeatable. The analyses also indicate that, although many individuals can be reliably re-identified, many others cannot. The ability to re-identify whales is primarily a function of the degree of scarring on the dorsal surface and, to a lesser extent, the amount of white pigmentation on the lower jaw and in the fluke/caudal region. The amount of scarring increases with the length (= age) of the whale. This leads to some age-related biases in the ability to re-identify bowheads. The relevant findings from the analyses in Appendices 1 to 3 are considered where appropriate in the following sections of the report.

Sampling Strategy

The main thrust of the study design was planned to be repeated intensive coverage of areas influenced by industrial activities to document residence times, movement patterns, and age structure of bowheads exposed to industrial activities. Less intensive coverage of nearby undisturbed control areas was planned. Two factors acted to force a change in emphasis of the sampling design. Unusually poor weather conditions plagued the industrial zones during our study and few whales occurred in these areas.

Weather Conditions

Current weather reports were available from the industrial zones at all hours of the day since the various drillsites, island sites, and dredge locations reported the weather frequently throughout the day. The two most important variables reported were ceiling and wind speed. Ceilings below 152 m (500 ft) were frequent as were days with freezing rain and/or snow squalls.

Wind speed affects our aerial photography through the effect of wind on the sea state. We have found (in 1982 and in this study) that even quite moderate waves and sea states create a great deal of wash when they meet a whale. This wash can badly obscure the back of the whale and even its snout and tail under some circumstances. Photographs under these conditions cannot be used either to measure or identify the whale. Hence, it is usually a waste of time and money to photograph whales in these conditions.

Good quality photographs can be obtained in conditions where sea states are 2 or less on the Beaufort Scale. Conditions are marginal during sea state 3 and unacceptable at sea states 4 or above. The mean wind speed for sea state 2 is 5 knots; for sea state 3 the mean wind speed is 9 knots and for sea state 4 it is 13 knots. Higher wind speeds can be tolerated for photography if large amounts of pan ice reduce the wind fetch.

The amount of coverage that we were able to obtain in various parts of the study area is summarized in Table 1. Conditions for photography were suitable in the North and South Industrial zones on only 7 days of the 31 day study period. This contrasted markedly with the King Point and Interface zones where photography was possible on at least 14 days. Small scale factors apparently influence weather patterns in these last two areas since, on several days, these were the only parts of the study area where useful photography was possible.

On the few days when photography was possible in the main industrial area (North and South Industrial zones), few bowheads were found in the area. The overall patterns of whale distribution in 1984 are discussed in the following sections. The point to note here is that the combination of poor weather and lack of whales in the industrial area caused us to greatly increase our coverage of the Interface Zone, which was industrialized in its NE section, and the King Point Zone, which was a relatively undisturbed area.

Table 1. Timing of aerial coverage in each of the seven sampling zones in the Canadian Beaufort Sea in August-September 1984.*

Date	Komakuk**	Herschel Island	King Point	Interface	South Industrial	North Industrial	Franklin Bay
14 Aug	–	–	–	–	X	X	–
15 Aug	–	–	X	–	–	–	–
16 Aug	–	+	X	X	–	–	–
17 Aug	–	X	X	X	–	–	–
18 Aug	X	X	X	X	–	–	–
19 Aug	–	–	–	X	–	–	–
21 Aug	–	–	–	+	X	+	–
22 Aug	–	–	–	–	X	X	–
23 Aug	–	–	–	–	–	–	X
24 Aug	–	–	X	X	–	–	–
27 Aug	–	–	X	–	–	–	–
28 Aug	–	–	–	–	X	X	–
29 Aug	–	–	–	–	X	–	–
30 Aug	X	X	X	X	–	–	–
31 Aug	–	X	X	X	–	–	–
1 Sep	–	–	–	–	–	–	X
2 Sep	–	X	X	X	X	X	–
5 Sep	–	–	–	–	X	X	–
6 Sep	–	–	–	–	–	–	X
11 Sep	–	X	X	–	–	–	–
12 Sep	–	–	X	X	–	–	–
14 Sep	X	X	–	X	–	–	–

* X = substantial coverage; + = minor coverage; – = no coverage.

** See Fig. 6 for locations of these zones.

Overall Distribution Patterns

In addition to coverage obtained in the present study, four other studies of bowheads obtained information on distribution patterns in the Canadian Beaufort Sea in summer 1984. (1) Systematic surveys of a large portion of the southeastern Beaufort Sea (including all of our study area) were conducted on two occasions (18-27 August and 6-18 September) by ESL Ltd. (Harwood and Borstad 1985). (2) Detailed behavioral observations and experiments were conducted throughout August in many parts of our study area by LGL Ltd. as part of a five year study funded by the U.S. Minerals Management Service (Richardson et al. 1985a). (3) Aerial surveys of bowheads in Alaskan waters occasionally extended into the western part of the Canadian

Beaufort Sea (Ljungblad et al. 1985a,b). (4) Photogrammetric work by the U.S. National Marine Mammal Lab, 13-17 August (D. Rugh, pers. comm.). Richardson et al. (1985d) summarized the data for all five 1984 studies (including the present study) on a series of distribution maps by 10 day intervals. The maps for the three periods from 11 August to 10 September are presented here as Figs. 7, 8 and 9.

Some care is required when evaluating Figs. 7-9 since the data presented have not been adjusted to reflect differential intensities of coverage in various areas. In addition, the data have not been corrected to reflect the different types of coverage. For example, many more whales are sighted in a particular area if the aircraft circles overhead for many minutes rather than making a single straight-line pass over the area. Thus, estimates of numbers of whales determined during photography or behavioral studies are not directly comparable to uncorrected transect survey results. Thus, Figs. 7-9 are very useful for indicating the overall gross distribution of bowheads throughout our study period but they are not useful for generating numerical estimates or fine-scale comparisons among areas.

It is clear from all three summary maps that bowheads were not evenly distributed through the area. Rather, major concentrations occurred along the interface between the Mackenzie River plume and more oceanic water, and along the Yukon coast in the King Point Zone; and minor concentrations occurred in the Herschel Island and Komakuk zones. It is also clear that few bowheads were present in either the North or South Industrial zones. Our main control area was in Franklin Bay, which is just east of the area covered in Figs. 7-9. Substantial numbers of whales were present in this area on the three dates when we photographed there (Table 1).

Distribution of Whale Lengths

The length distribution of the photographed sample of whales is derived and presented in Appendices 1 and 2. Overall, 488 length measurements of Grades 1 to 6 were obtained (see Table 21 and Fig. 33 in Appendix 2). These data include each measurement of a whale even if there was more than one photograph of a particular whale. When these duplicate measurements were

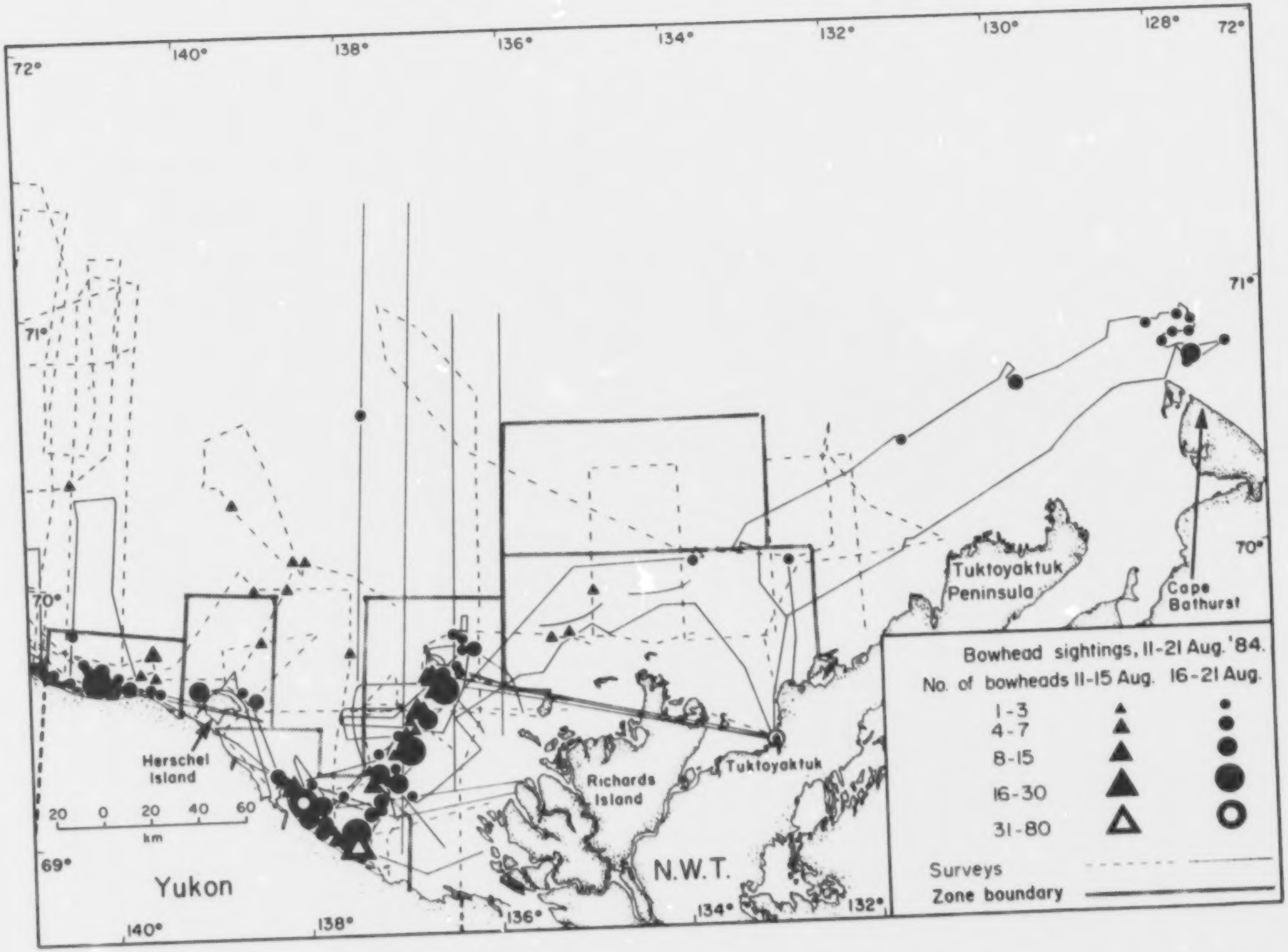
72°
140°
138°
136°
134°
132°
130°
128°
72°
71°
71°
70°
70°
69°
Tuktoyaktuk Peninsula
Cape Bathurst
Herschel Island
Richards Island
Tuktoyaktuk
Yukon
N.W.T.
20 0 20 40 60
km
140°
138°
136°
134°
132°
Bowhead sightings, 11-21 Aug. '84.
No. of bowheads 11-15 Aug. 16-21 Aug.
1-3
4-7
8-15
16-30
31-80
Surveys
Zone boundary

FIG. 7. Distribution of bowhead whales in the southeastern Beaufort Sea, 11-21 August 1984 (from Richardson et al. 1985d).

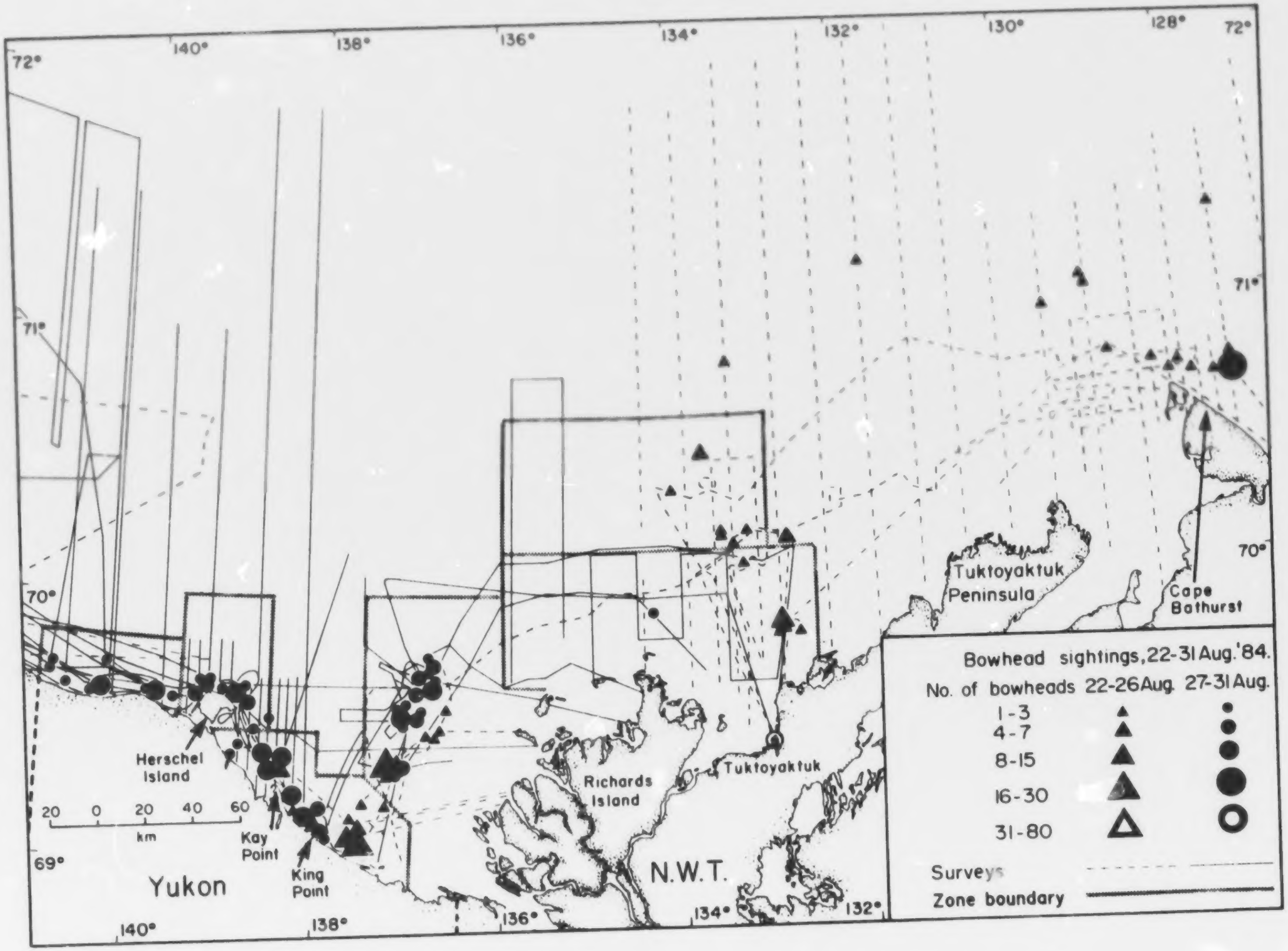
72°
140°
138°
136°
134°
132°
130°
128°
72°
71°
71°
70°
70°
69°
Tuktoyaktuk Peninsula
Cape Bathurst
Tuktoyaktuk
Richards Island
Herschel Island
Kay Point
King Point
Yukon
N.W.T.
20 0 20 40 60
km
140°
138°
136°
134°
132°
Bowhead sightings, 22-31 Aug. '84.
No. of bowheads 22-26 Aug. 27-31 Aug.
1-3
4-7
8-15
16-30
31-80
Surveys
Zone boundary

FIG. 8. Distribution of bowhead whales in the southeastern Beaufort Sea, 22-31 August 1984 (from Richardson et al. 1985d).

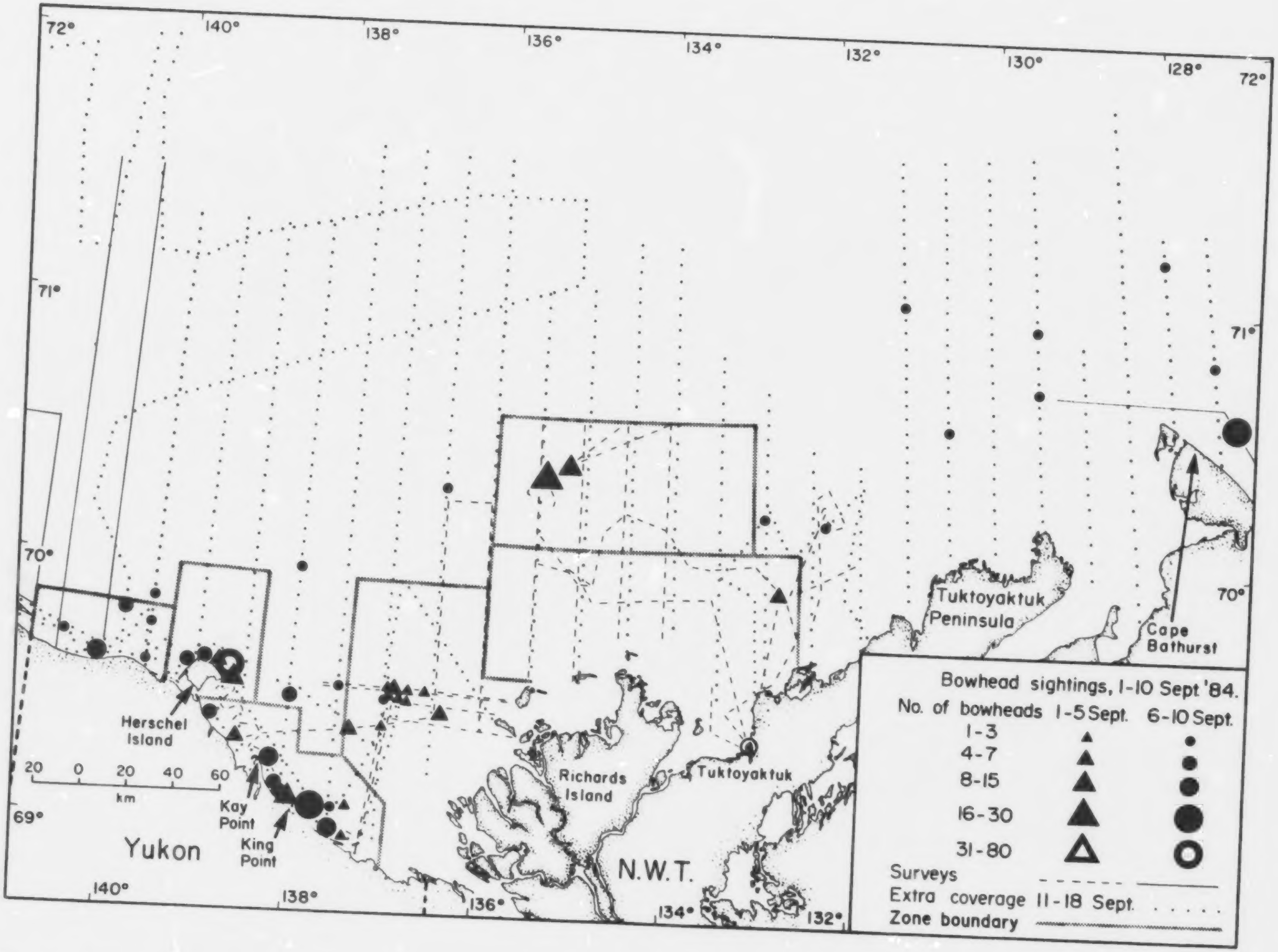
72°
140°
138°
136°
134°
132°
130°
128°
72°
71°
71°
70°
70°
69°
Tuktoyaktuk Peninsula
Cape Bathurst
Herschel Island
Kay Point
King Point
Yukon
Richards Island
Tuktoyaktuk
N.W.T.
20 0 20 40 60
km
140°
138°
136°
134°
132°
Bowhead sightings, 1-10 Sept '84.
No. of bowheads 1-5 Sept. 6-10 Sept.
1-3
4-7
8-15
16-30
31-80
Surveys
Extra coverage 11-18 Sept.
Zone boundary

FIG. 9. Distribution of bowhead whales in the southeastern Beaufort Sea, 1-10 September 1984 (from Richardson et al. 1985d).

removed, there were 391 length measurements of different whales (Fig. 35 in Appendix 2). All but one of these measurements were of whales that were photographed in our seven study zones. The length distributions of whales in each of these zones are discussed in subsequent sections of this report. Before these discussions, it is worthwhile to present the current understanding of the relationship between the age and length of bowhead whales.

Whale Length vs. Age

The length at which male bowheads become sexually mature is not known but for the purposes of this study we will assume that males and females become sexually mature at the same length (= age?). Nerini et al. (1984), based on a sample of 14 harvested sexually mature females, concluded that females become sexually mature at a length of 14 m. However, their sample of fully-examined animals between 12 and 14 m in length was very small. Davis et al. (1983), using the photogrammetric technique employed in the present study, found that 91% of the 23 females accompanied by calves in 1982 were over 13.5 m long. Only one animal between 13.0 and 13.5 m had a calf and only one (2%) of 44 animals 12-13 m long was accompanied by a calf. Since females are actually sexually mature in the year before they first have a calf, we assume in this report that 13 m is the size of sexual maturity. The 1983 data in Cubbage et al. (1984) also support the validity of this assumption.

Davis et al. (1983) measured 42 different calves in the 12 August-5 September period in 1982. These calves ranged in length from 4.1 to 7.6 m (mean = 6.45 m ± 0.695 s.d.). Cubbage et al. (1984) found similar results in 1983, although they believed that a 7.84 m animal was a calf. In the present study we assume that all whales less than 7.5 m in length are calves of the year.

The length interval that represents yearling bowheads is not well understood. Davis et al. (1983) tentatively concluded that animals 7.9 to 8.7 m long during late summer of 1982 were yearlings. Nerini et al. (1984) analyzed the lengths of 88 bowheads taken in spring in Alaska during

1973-82. They found a significant grouping of animals centred at 8.2 m with an approximate range from 6.6 to 9.2 m in length. Assuming that some growth occurs between the April-early June period of the spring hunt and the late August period of the photography studies, it is possible that some yearlings could reach 10 m by late August. Larger sample sizes will be needed to clarify the situation.

Overall Patterns

The lengths of the bowheads photographed in each of the seven study zones are presented in Table 2 and Fig. 10. Visual inspection of Fig. 10 indicates that major differences in the length distribution, and hence age structure, occurred among some of the seven study zones. Large animals were apparently restricted primarily to the North Industrial and Franklin Bay zones. The data in Table 2 were tested using a G test to determine whether the length distribution patterns were the same in each zone. (The South Industrial Zone and 'Other Areas' were excluded due to small sample sizes and expected values.) The results showed a highly significant difference among the six remaining zones ($G = 237.8$, $df = 35$, $P<0.001$).

The length-frequency distributions in the six zones were compared using the *a posteriori* STP test follow-up to the G test (Sokal and Rohlf 1969). No significant differences were found among the distributions in the Komakuk, Herschel Island, King Point, and Interface zones ($G = 42.4$, $df = 35$, $P>0.1$). There was also no difference between the North Industrial and Franklin Bay zones ($G = 8.7$, $df = 1$, $P>0.9$). All other possible comparisons showed significantly different whale lengths.

One of the most striking findings in 1984 was the almost total lack of potentially breeding adult whales along the Yukon coast and in the potentially disturbed Interface Zone and the South Industrial Zone. In these five zones, the percentage of the whales that were adults ranged from 0 to 5, whereas the percentage of whales that were non-calf immature animals ranged from 93 to 100 (Table 3). In the North Industrial and Franklin Bay zones, the percentages of the whales that were potentially breeding adults were 59

Table 2. Length-frequency distributions of whales (known duplicates excluded) photographed in different geographic zones in the Canadian Beaufort Sea, 14 August-14 September 1984. All lengths are in metres.

Zone	<7.50	7.50-9.00	9.01-10.00	10.01-11.00	11.01-12.00	12.01-13.00	13.01-14.00	14.01+	Total	Mean ± s.d.
Komakuk	1	7	13	4	1	0	1	0	27	9.52 ± 1.36
Herschel Island	2	13*	10	22	13	4	2	1	67	10.32 ± 1.67
King Point	4	41*	21	27	7	4	1	3	108	9.66 ± 1.64
Interface	1	12	17	13	8	10	1	2	64	10.42 ± 1.70
South Industrial	0	2	1	3	2	0	0	0	8	10.23 ± 1.06
North Industrial	0	1	2	0	3	7	10	9	32	13.06 ± 1.61
Franklin Bay	2	3	1	7	9	22	24	17	85	12.58 ± 1.82
Other Areas	0	0	0	0	0	0	1	0	1	13.07
Total	10	79*	65	76	43	47	40	32	392*	10.82 (n = 391)

* Includes one whale that moved from the Herschel Island to the King Point Zone. Thus, total n = 78 different whales in 7.5-9.0 m class.

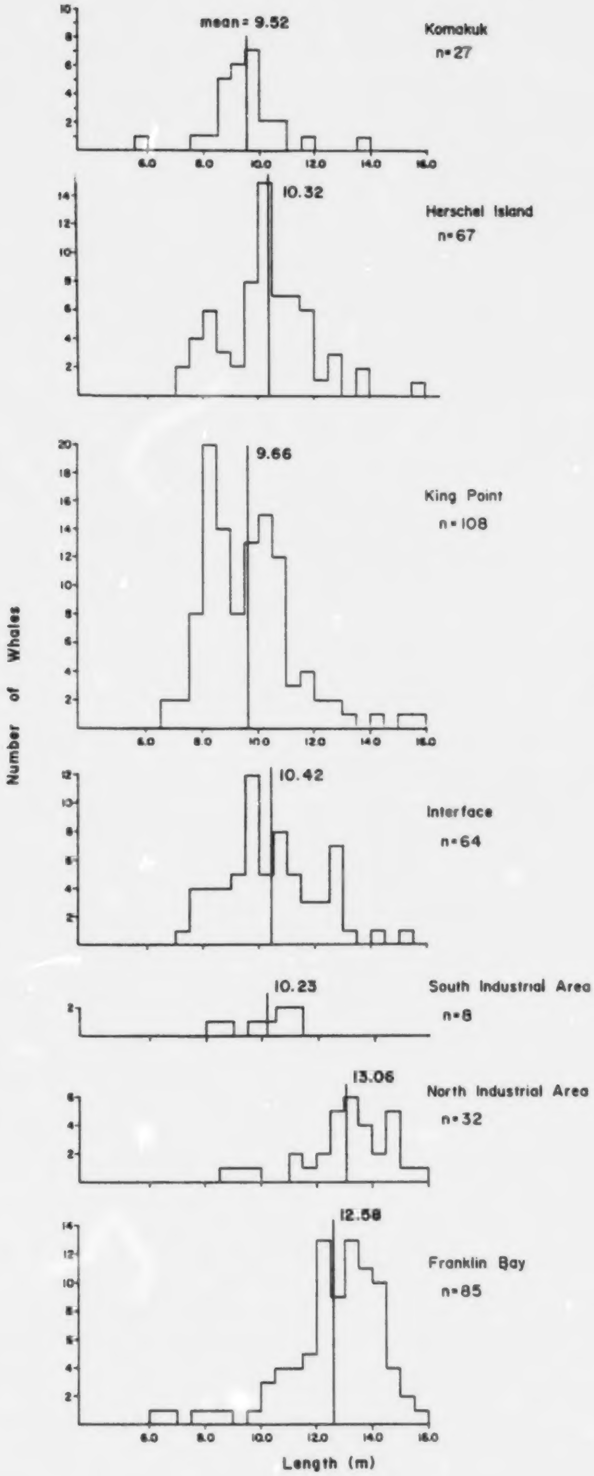

FIG. 10. Length-frequency distributions of whales (duplicate lengths excluded) photographed in seven zones in the Canadian Beaufort Sea, 14 August-14 September 1984.

Table 3. Numbers and percentages of whales (known duplicates excluded) of various reproductive classes in the seven study zones in the Canadian Beaufort Sea, 14 August-14 September 1984.

	Calf	Immature	Adult	
Zone	<7.50 m	7.5-13.0 m	>13 m	Totals
Komakuk	1 (4%)	25 (93%)	1 (4%)	27
Herschel Island	2 (3)	62 (93)	3 (4)	67
King Point	4 (4)	100 (93)	4 (4)	108
Interface	1 (2)	60 (94)	3 (5)	64
South Industrial	0 (0)	8 (100)	0 (0)	8
North Industrial	0 (0)	13 (41)	19 (59)	32
Franklin Bay	2 (2)	42 (49)	41 (48)	85
Totals	10 (3)	310 (79)	71 (18)	391

and 48%, respectively. Also, most of the non-calf immatures in these last two zones were relatively large 11-13 m whales (Table 2).

The data indicate that pronounced age segregation occurred in our 1984 study area. It is clear that not all age classes were equally exposed to potential disturbance from industrial activities. In addition, none of our seven study zones contained the high proportion of very large 15-18 m whales that was found in deSalis Bay, Banks Island, in 1981 (Davis et al. 1982) and to a lesser extent in Franklin Bay in 1983 (Cubbage et al. 1984).

North and South Industrial Zones

Coverage

As discussed earlier, our coverage of these areas was less intensive than desired due to persistent poor weather conditions in the area (Table 1). The actual aerial coverage in these two zones is shown in Figs. 11, 12 and 13.

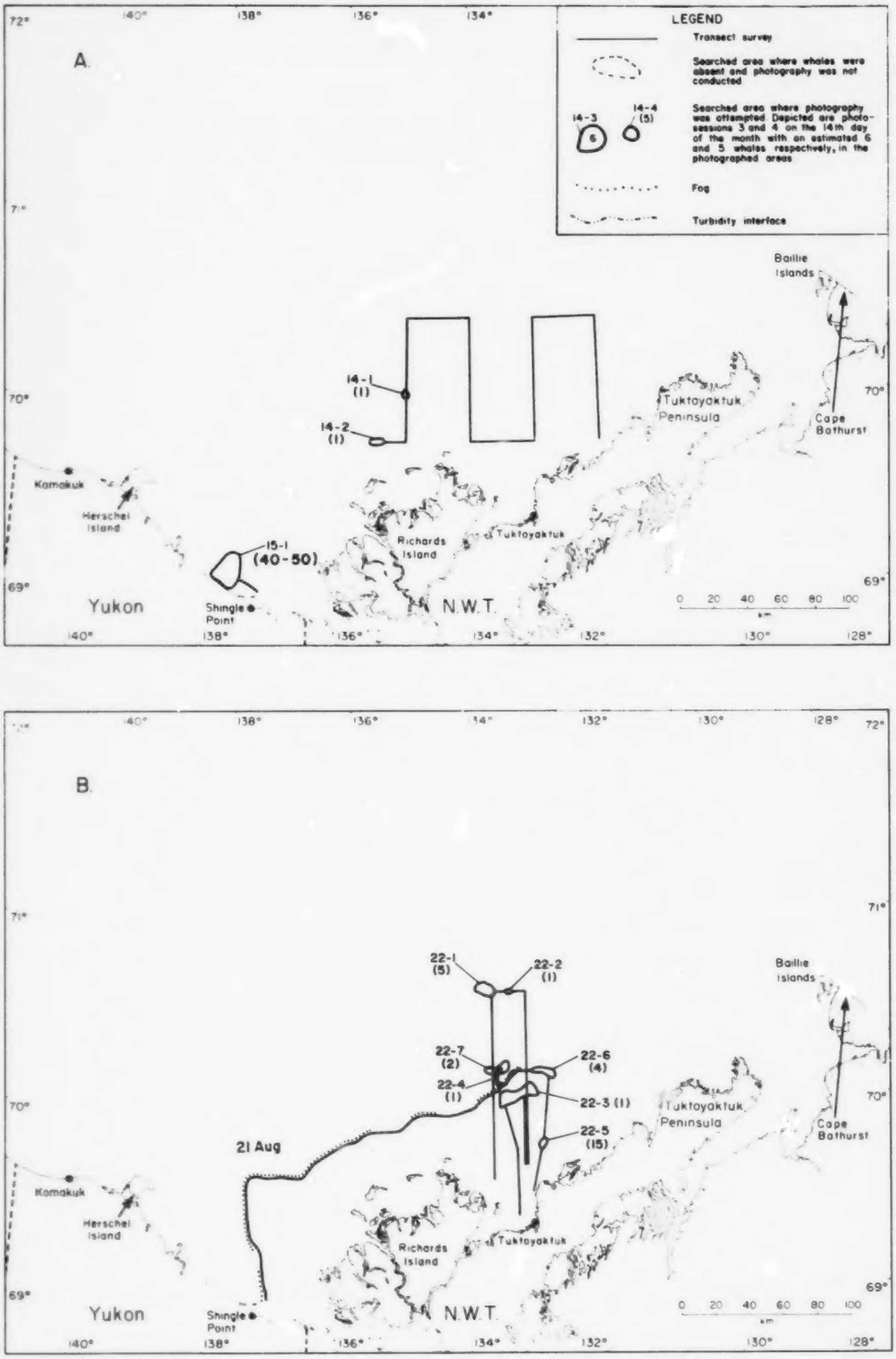
A.
LEGEND
Transect survey
Searched area where whales were absent and photography was not conducted
14-3
6
14-4
(5)
Searched area where photography was attempted. Depicted are photo-sessions 3 and 4 on the 14th day of the month with an estimated 6 and 5 whales respectively, in the photographed areas
Fog
Turbidity interface
72°
71°
70°
69°
140°
138°
136°
134°
132°
130°
128°
14-1
(1)
14-2
(1)
15-1
(40-50)
Baillie Islands
Tuktoyaktuk Peninsula
Cape Bathurst
Komakuk
Herschel Island
Richards Island
Tuktoyaktuk
Yukon
Shingle Point
N.W.T.
0 20 40 60 80 100
km
B.
22-1
(5)
22-2
(1)
22-7
(2)
22-6
(4)
22-4
(1)
22-3 (1)
22-5
(15)
21 Aug

FIG. 11. Locations of aerial surveys and photographic sessions conducted on 14-15 August (A) and 21-22 August (B) 1984.

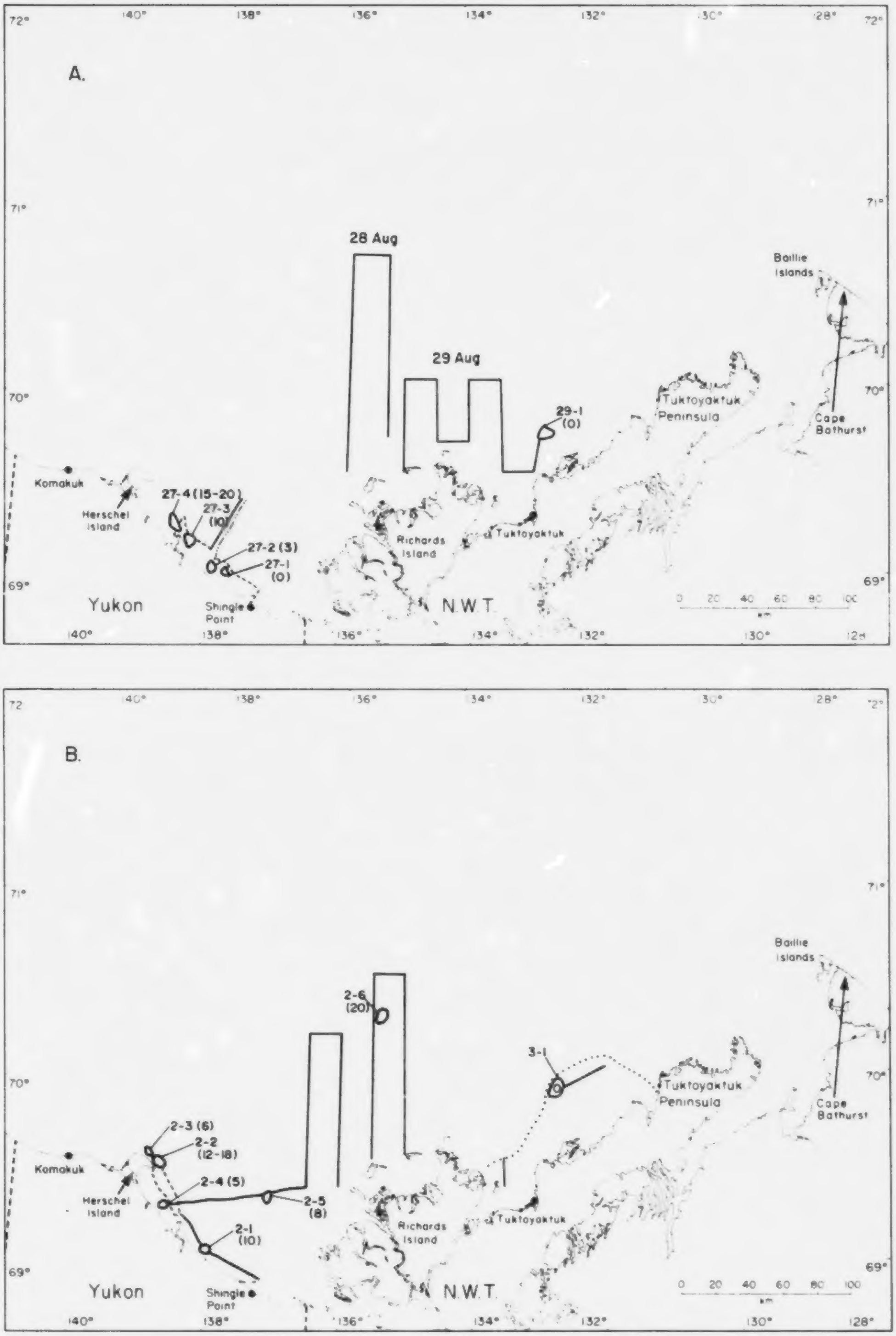
A.
72°
140°
138°
136°
134°
132°
130°
128°
71°
70°
69°
28 Aug
29 Aug
Baillie Islands
Tuktoyaktuk Peninsula
Cape Bathurst
29-1 (0)
Komakuk
Herschel Island
27-4 (15-20)
27-3 (10)
27-2 (3)
27-1 (0)
Richards Island
Tuktoyaktuk
Yukon
Shingle Point
N.W.T.
0 20 40 60 80 100
km
B.
2-6 (20)
3-1
2-3 (6)
2-2 (12-18)
2-4 (5)
2-5 (8)
2-1 (10)

FIG. 12. Locations of aerial surveys and photographic sessions conducted on 27-29 August (A) and 2 September (B) 1984.

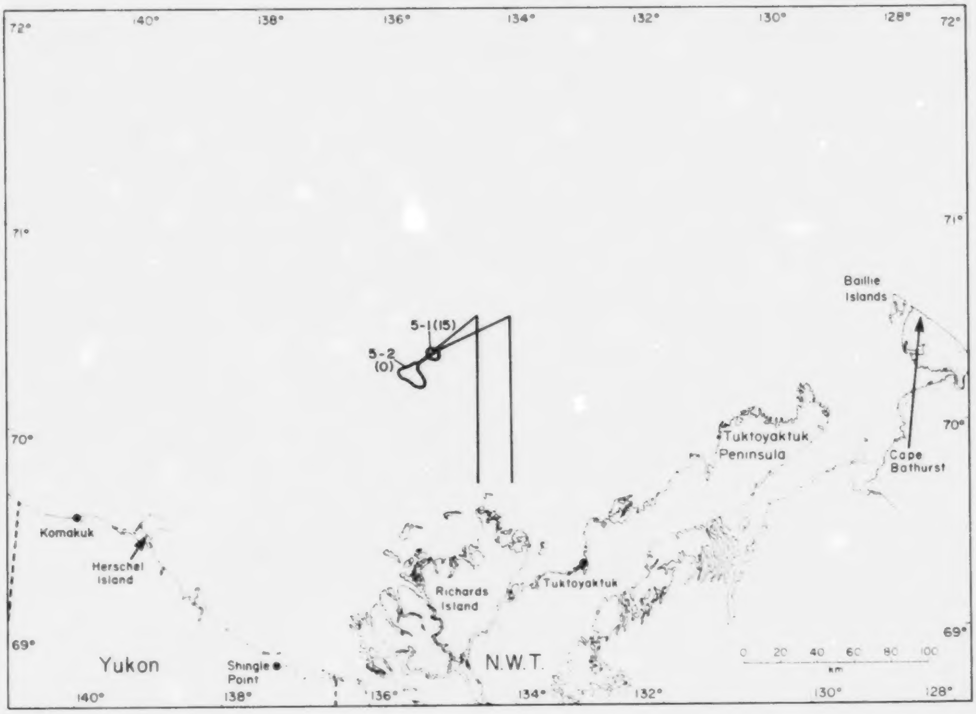
72°
140°
138°
136°
134°
132°
130°
128°
72°
71°
71°
Baillie Islands
5-1(15)
5-2 (0)
70°
70°
Tuktoyaktuk Peninsula
Cape Bathurst
Komakuk
Herschel Island
Richards Island
Tuktoyaktuk
69°
69°
Yukon
Shingle Point
N.W.T.
0 20 40 60 80 100
km
140°
138°
136°
134°
132°
130°
128°

FIG. 13. Locations of aerial surveys and photographic sessions conducted on 5 September 1984.

Distribution

The numbers and distributions of whales in these zones were quite variable from day to day. Few bowheads were present on 14 August but whales were widespread in small numbers on 22 August. However, by 28-29 August whales were apparently absent. We made a particular effort to follow the group of whales in area 22-5 (Fig. 11B) in the South Industrial Zone. These whales were near an abandoned artificial island (Alerk) about 45 km north of Tuktoyaktuk on 22 August. We originally estimated that 15 whales were present in the very turbid water of the area but subsequent analyses of photographs indicated that at least 20 whales were present (Table 4). An intensive search of this general area on 29 August indicated that this group had left the area sometime previously. W.J. Richardson (LGL Ltd., pers. comm.) found only three in this area during behavioral studies on 23 August and found none here during overflights on 28 August and 1 September.

Table 4. Estimated numbers of whales, numbers of photographs of usable quality, and number of measured whales during each photographic session in the South Industrial Zone, 14 August-3 September 1984.

Photo Session	Estimated Number of Whales	Number of Grade A and B Photos	Number of Different Whales with Grade A and B Photos	Number of Different Whales with Grade A Photos	Number of Different Measured Whales*
14-1	1	0	0	0	1
14-2	1	0	0	0	-
22-3	1	-	-	-	-
22-5	15	28	20	1	7
29-1	0	-	-	-	-
3-1	0	-	-	-	-
Totals	18	28	20	1	8

* Grades 1-6 only.

The group of whales in area 22-5 referred to above were in the eastern edge of the 'industrialized area' in 1984. The inactive artificial island Alerk (symbol Ale) on Fig. 4 was in area 22-5. Reference to Fig. 4 illustrates that this group of whales was undoubtedly exposed to industrial noise and disturbance.

Aerial coverage found a group of 23 bowheads in the North Industrial Zone on 2 September (Fig. 12B, Table 5) and a group estimated at 15 whales about 5 km northeast on 5 September (Fig. 13). The group found on 2 September was intensively photographed (62 photographs of 23 whales--Table 5) and consisted of well-marked whales. Unfortunately, few (3) good quality photographs could be obtained on 5 September due to high sea states. Nonetheless, none of the three whales photographed on 5 September were present in the group on 2 September when very intensive coverage (62 photos of 23 whales) was obtained. We tentatively conclude that two different groups may have been involved, and that they consisted of animals moving

Table 5. Estimated numbers of whales, numbers of photographs of usable quality, and number of measured whales during each photographic session in the North Industrial Zone, 21 August-5 September 1984.

Photo Session	Estimated Number of Whales	Number of Grade A and B Photos	Number of Different Whales with Grade A and B Photos	Number of Different Whales with Grade A Photos	Number of Different Measured Whales*
22-1	5	5	5	4	3
22-2	1	0	0	0	0
22-4	1	1	1	1	1
22-6	4	6	2	1	2
22-7	2	-	-	-	-
2-6	20	62	23	16	23
5-1	15	3	3	1	3
5-2	0	-	-	-	-
Totals	48	77	34	23	32

* Grades 1-6 only.

through the area. This incident provides a good example of the errors that can arise if groups of whales in the same area on different days are assumed to consist of the same animals.

The group of at least 23 animals in area 2-6 was about 12 km north of the drillship Canmar Explorer III, which was active at the Arluk site (symbol Arl on Fig. 4). The group of 15 whales in area 5-1 on 5 September was about 23 km northeast of the Arluk site. We have no coincident measurements of underwater noise from the Arluk or any other of the offshore drillsites.

Numbers

Systematic transect surveys were conducted in the North and South Industrial zones as part of this study and by Harwood and Borstad (1985). The data from the two studies, which used similar survey techniques, are presented in Table 6. Clearly, very few whales were present in these areas

Table 6. Systematic aerial survey coverage within the North and South Industrial zones, 14 August-12 September 1984.

Survey Date	Area Surveyed (sq km)	Number of Whales Seen 'On Transect' (Off Transect)	Density (Whales/ 1000 sq km)
14 Aug	617	1 (1)	1.62
18 Aug*	224	0 (0)	0.00
22 Aug*	544	1 (0)	1.84
22 Aug	249	0 (1)	0.00
28 Aug	397	0 (0)	0.00
29 Aug	557	0 (0)	0.00
2 Sep	518	0 (4)	0.00
5 Sep	258	0 (0)	0.00
11 Sep*	1040	0 (0)	0.00
12 Sep*	508	0 (0)	0.00
Total	4912	2 (6)	0.41

* Survey conducted by Harwood and Borstad (1985).

during the study. Whales were seen on the transect strip during only two of the nine days on which surveys were flown. The overall average density was very low (0.41/1000 sq km).

The aerial surveys (Table 6) and aerial photography (Figs. 11, 12 and 13) both suggest that maximum numbers of bowheads were present in the North and South Industrial zones on or about 22 August. The density of whales (0.00184/sq km) on this date can be applied to the size of the combined zones (13,400 sq km) to produce an uncorrected estimate of the numbers present. This estimate can then be corrected using data derived by Davis et al. (1982) to account for whales at the surface that are not seen by surveyors (x 1.46) and whales that are submerged and not visible to the surveyors (x 3.83). These calculations suggest that there was a maximum of only 138 bowheads in the combined North and South Industrial zones at one time in 1984.

Length Distribution

Only eight length measurements (mean 10.2 m) were obtained in the South Industrial Zone (Fig. 14). Seven of these measurements came from the group of 20 whales photographed in area 22-5 on 22 August (Fig. 11, Table 4). The group consisted of small, immature animals ranging in length from 8 to 11.5 m; thus, some yearlings were present (Fig. 14). Few of the 28 photographs taken provided usable length measurements because the water in area 22-5 was very turbid. In addition, the water depth was very shallow (10-15 m). The single whale photographed in area 14-1 on 14 August was also small (11.1 m); it was in 30-50 m of water.

A total of 32 length measurements of different bowheads were obtained in the North Industrial Zone (Fig. 15). Most of these animals were much larger than those in the South Industrial Zone. Overall, 81% of the whales were longer than 12 m. This pattern of mostly large animals prevailed on each of the three days with photographs, although two of the samples are small. Overall, the mean length of measured animals was 13.1 m (Table 2). The whales in the North Industrial Zone were generally in fairly clear water 30-100 m deep. Also, as noted earlier, the whales apparently did not linger

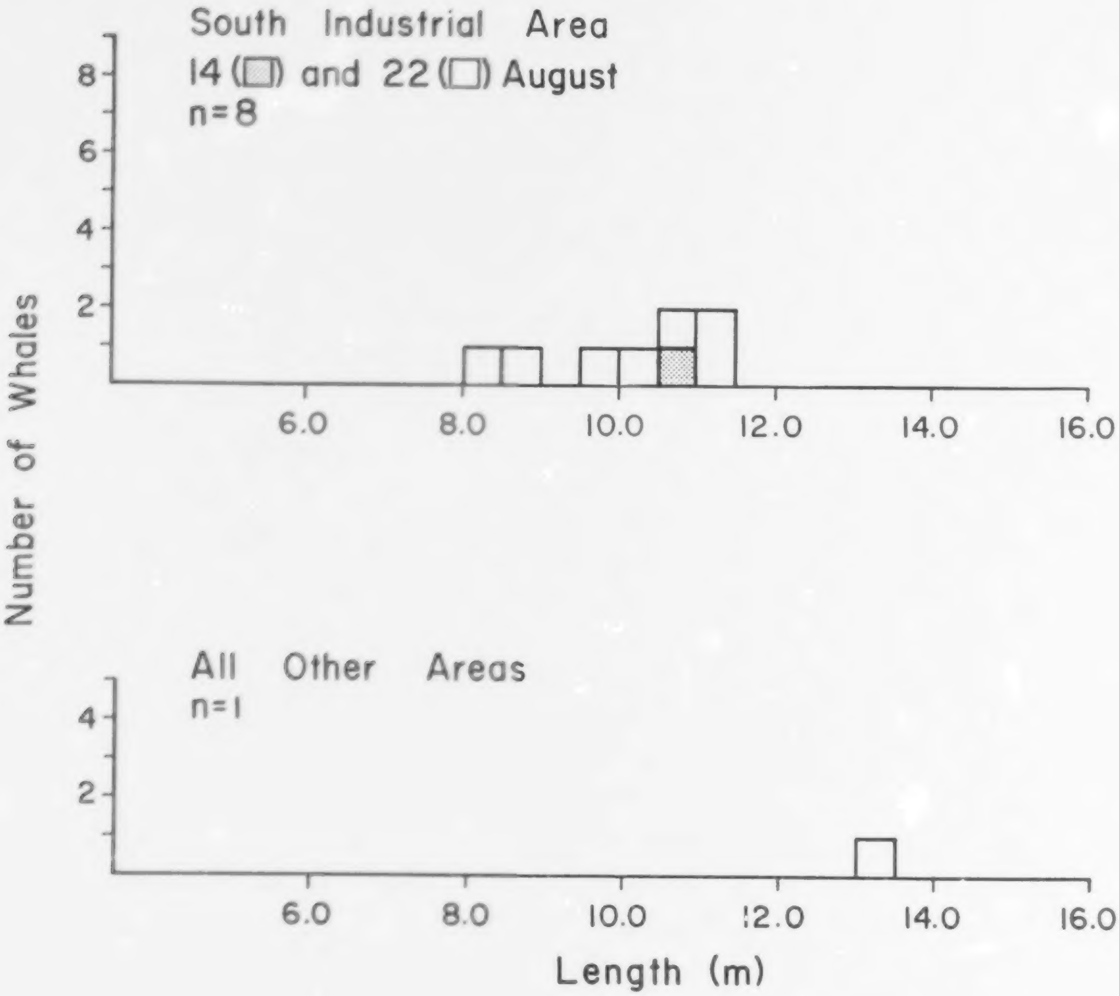

FIG. 14. Length-frequency distributions of bowhead whales photographed in the South Industrial Zone and outside the primary study area, 14 August-11 September 1984.

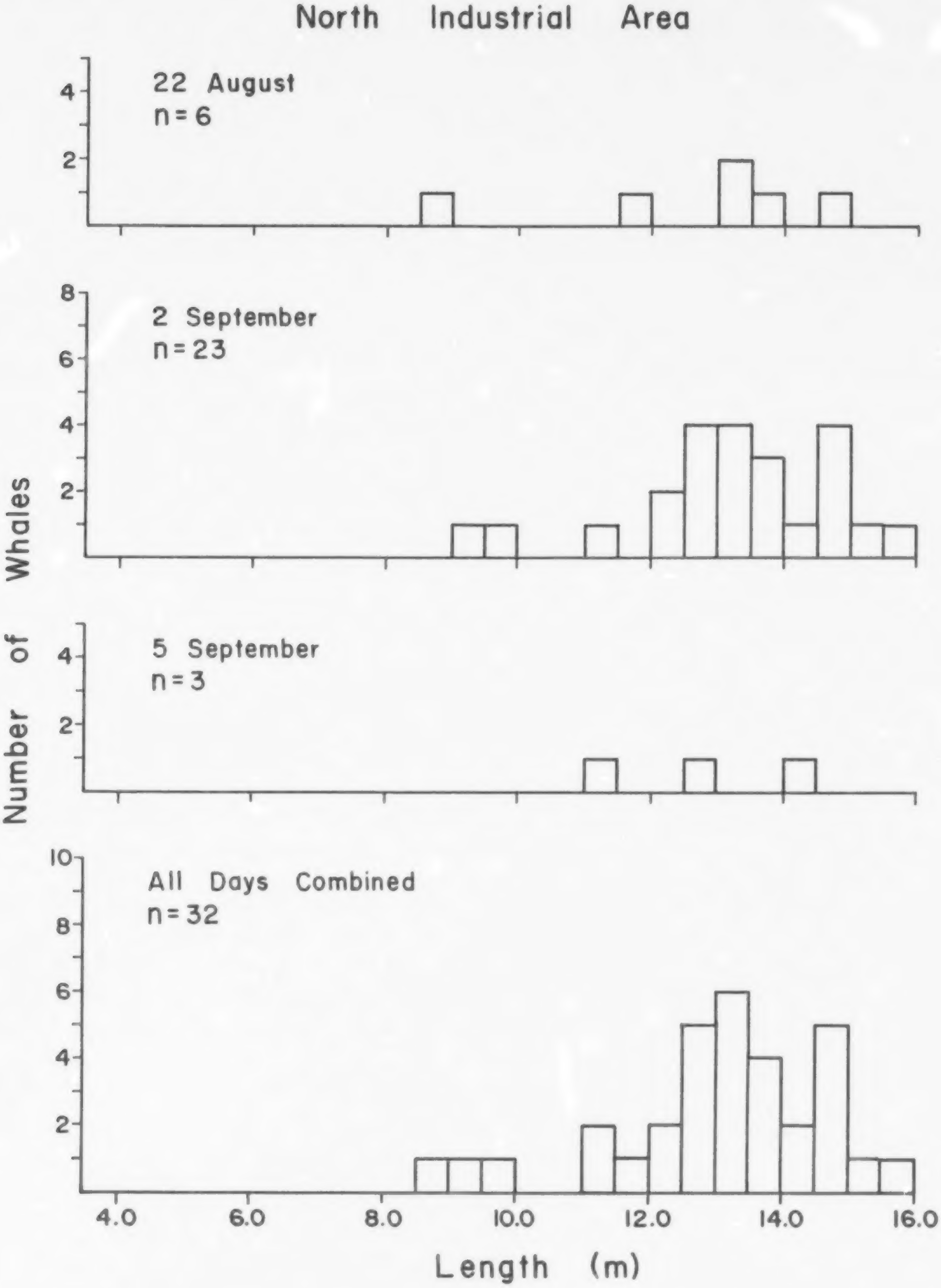

FIG. 15. Length-frequency distributions of bowhead whales photographed in the North Industrial Zone, 22 August-5 September 1984.

for long periods in this zone, although more frequent and larger samples would have been helpful.

Franklin Bay

Coverage

The Franklin Bay Zone was selected to serve as an undisturbed control area. Aerial surveys and photography were conducted there on 23 August and on 1 and 6 September (Fig. 16). In addition to our coverage, Harwood and Borstad (1985) conducted systematic surveys in Franklin Bay on 23 August and on 13 and 18 September. Richardson et al. (1985d) searched for whales near Cape Bathurst on 5, 9 and 23 August, as did the U.S. National Marine Mammal Lab on 17 August (Fig. 7; from D. Rugh, pers. comm.).

Distribution

Two general areas of Franklin Bay were frequented by bowheads. Groups of whales were found offshore (east) and southeast of the Horton River on all three days that we searched in Franklin Bay (Fig. 16). In addition, whales were found off the northeast end of Cape Bathurst on the two days that we covered this area (23 August and 6 September) and on three earlier dates (5, 9 and 17 August; Richardson et al. 1985d; D. Rugh, pers. comm.; see Fig. 7). Harwood and Borstad (1985) did not find bowheads in the latter area on 13 September but whales were still present off the Horton River on 18 September. Several inter-day re-identifications of individual whales also suggested that whale distribution patterns in Franklin Bay were relatively stable. (See later sections of this report for a full discussion of between-day re-identifications.)

Numbers

Systematic aerial surveys in Franklin Bay were conducted on 23 August by Harwood and Borstad (1985). They conducted intensive surveys (50% coverage) of the area extending from offshore of the Horton River south for about 40 km; the area included our photographic area 23-3 (Fig. 16A). Harwood and

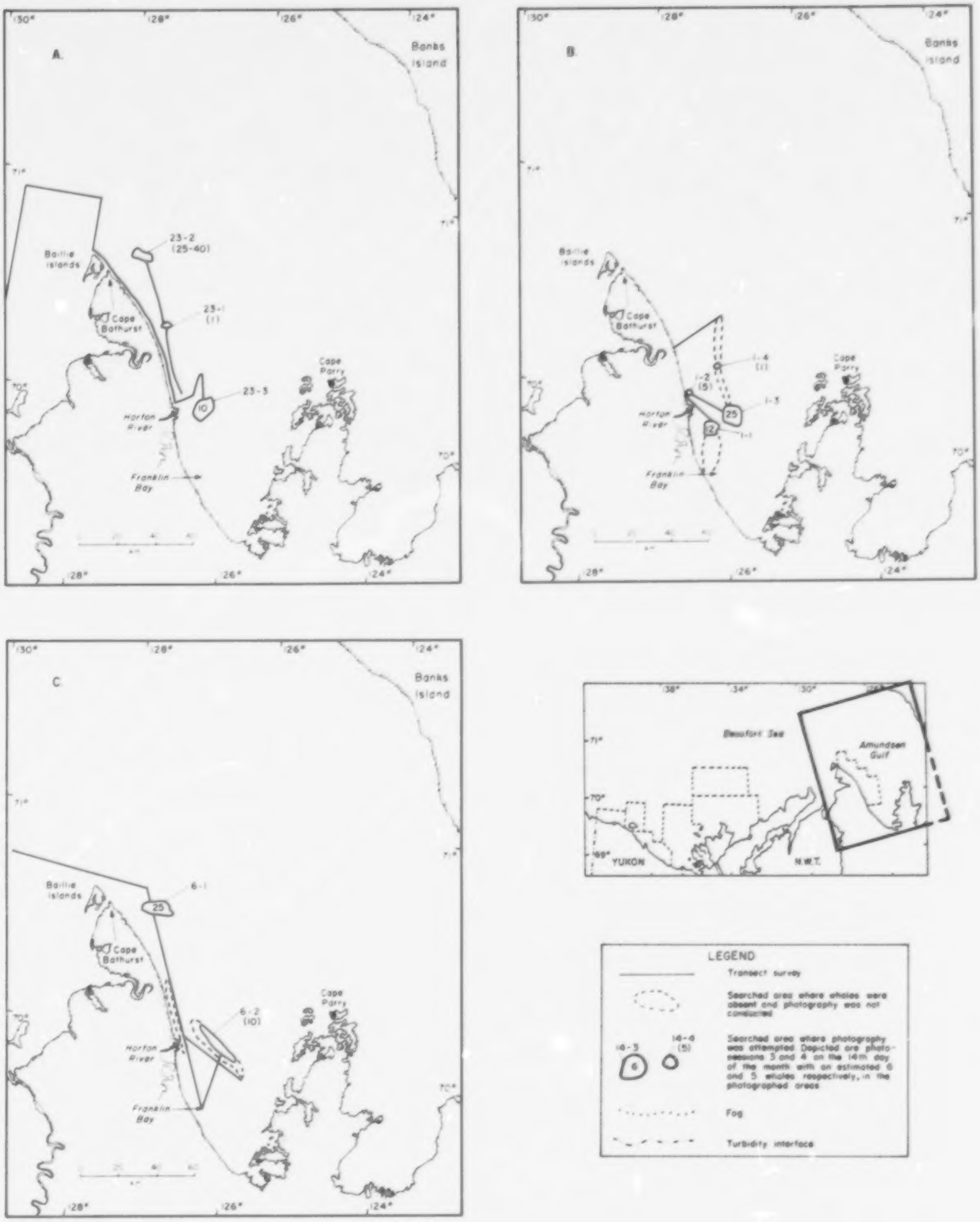
A.
130°
128°
126°
124°
Banks Island
71°
70°
Baillie Islands
Cape Bathurst
23-2
(25-40)
23-1
(1)
23-3
10
Cape Parry
Horton River
Franklin Bay
0
20
40
60
km
B.
1-4
(1)
1-2
(5)
1-3
25
12
1-1
C.
6-1
25
6-2
(10)
138°
134°
130°
126°
Beaufort Sea
Amundsen Gulf
69°
YUKON
N.W.T.
LEGEND
Transect survey
Searched area where whales were absent and photography was not conducted
14-3
6
14-4
(5)
Searched area where photography was attempted. Depicted are photo-sessions 3 and 4 on the 14th day of the month with an estimated 6 and 5 whales respectively, in the photographed areas
Fog
Turbidity interface

FIG. 16. Locations of aerial surveys and photographic sessions conducted on 23 August (A), 1 September (B), and 6 September (C) 1984 in Franklin Bay.

Borstad (1985) estimated that 100-200 bowheads were present in this 1000 sq km area. They estimated that about 100 animals were present (30% coverage) in a similar-sized zone at the north end of Cape Bathurst. Both of these estimates include corrections for unseen surfaced and sub-surfaced whales.

The semi-quantitative data from the photography sessions suggest that major changes in overall numbers of whales in Franklin Bay did not occur during the 23 August-6 September period (Table 7; Fig. 16), although some turnover of individuals probably occurred (see later sections).

Length Distribution

Whale photography was attempted on nine occasions during the three days of coverage in Franklin Bay (Table 7). Usable length measurements were obtained in eight of the sessions. A total of 85 different whales were measured. In general, the bowheads in Franklin Bay were large, averaging

Table 7. Estimated numbers of whales, numbers of photographs of usable quality, and number of measured whales during each photographic session in Franklin Bay, 23 August-6 September 1984.

Photo Session	Estimated Number of Whales	Number of Grade A and B Photos	Number of Different Whales with Grade A and B Photos	Number of Different Whales with Grade A Photos	Number of Different Measured Whales*
23-1	1	1	1	1	0
23-2	33 (25-40)	43	33	14	19
23-3	10	11	10	7	9
1-1	12	23	11	3	7
1-2	5	9	9	2	2
1-3	25	43	33	10	22
1-4	1	3	1	1	1
6-1	25	40	30	9	17
6-2	10	13	13	5	11
Totals	122	186	141	52**	88***

* Grades 1-6 only.

** Representing 49 different whales (three whales with grade A photographs were photographed on each of two different dates).

*** Representing 85 different whales (three whales were measured on two different days).

12.6 m (Table 2). Fully 74% (63 of 85) of the whales in Franklin Bay were over 12 m in length.

Over the study period there was a gradual increase in the proportion of small (8-12 m) whales in Franklin Bay (Fig. 17). Calves were detected only on the last day of coverage, 6 September. Two calves were present in the group of whales in area 6-1 off the NE end of Cape Bathurst (Fig. 16) rather than in the other concentration area off the mouth of the Horton River.

Most of the whales photographed and measured in Franklin Bay were in water at least 100 m deep. Only the group at area 1-2 on 1 September was in shallow water. This group of nine animals (based on photographs) was close to shore in water about 30 m deep. Only two measurements could be obtained in this relatively murky area. Both animals were probably yearlings, since they were less than 9 m in length.

Interface Zone

The Interface Zone was defined to include the western portion of the highly visible boundary or interface between the turbid Mackenzie River plume and clearer adjacent waters. The location of the plume edge varied within and between days; it also varied in its distinctness, ranging from a sharp, clearcut line to a zone of indistinct patches of different colored water. It should be noted that even when the interface was distinct, the differences in water clarity were only relative. Thus, the water on the west side of the interface was often quite turbid even though it was relatively clear compared with the very turbid water east of the interface. The turbid waters in the Interface Zone plagued the photographic analyses throughout the study.

Coverage

Aerial coverage of the Interface Zone during this project was quite intensive, with surveys and/or photography occurring on 11 different days between 16 August and 14 September (Table 1). The distributions of these activities are summarized in Figs. 11, 18, 19 and 20.

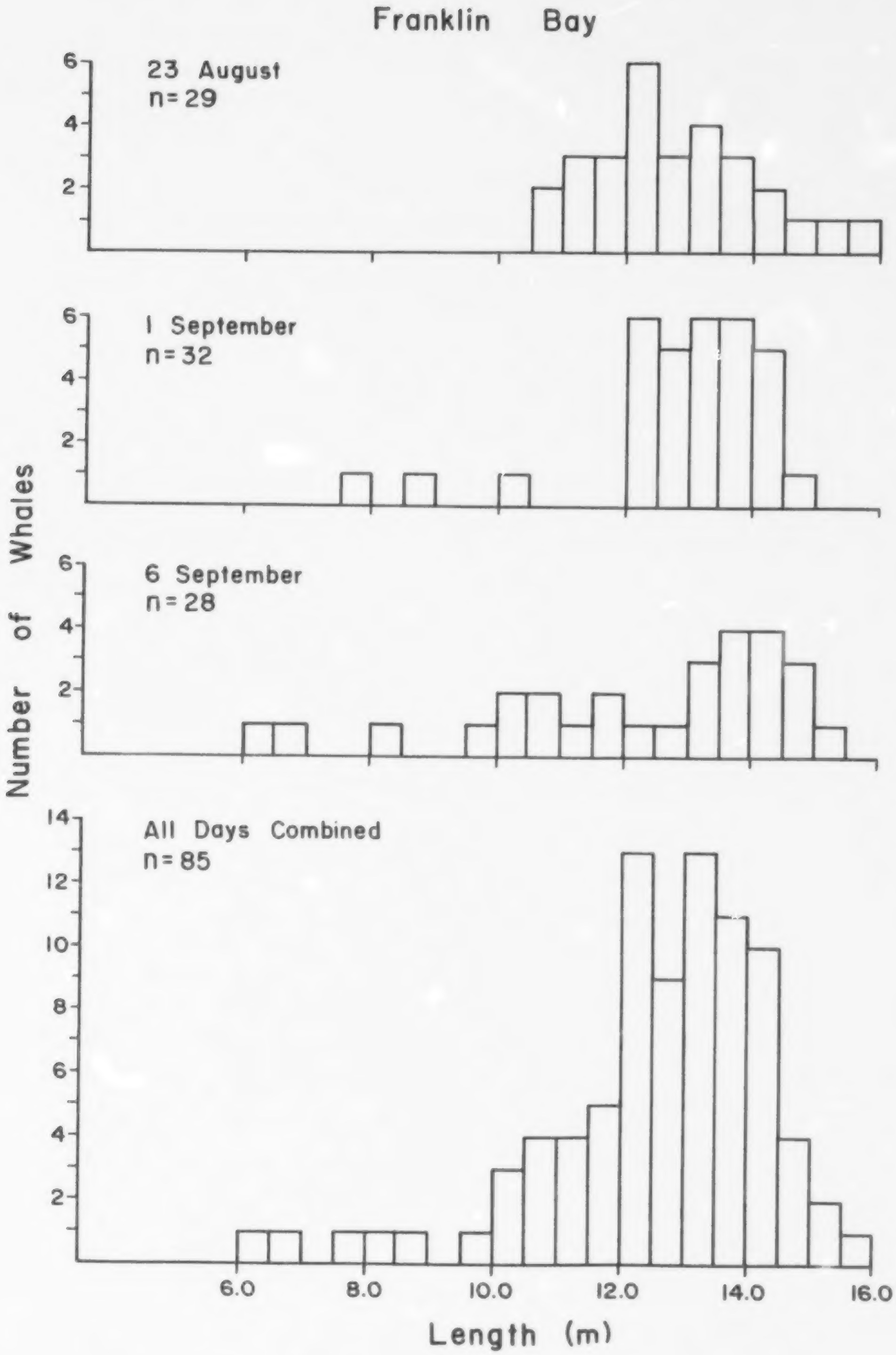

FIG. 17. Length-frequency distributions of bowhead whales photographed in Franklin Bay, 23 August-6 September 1984. Combined total excludes second measurements of whales photographed on more than one day.

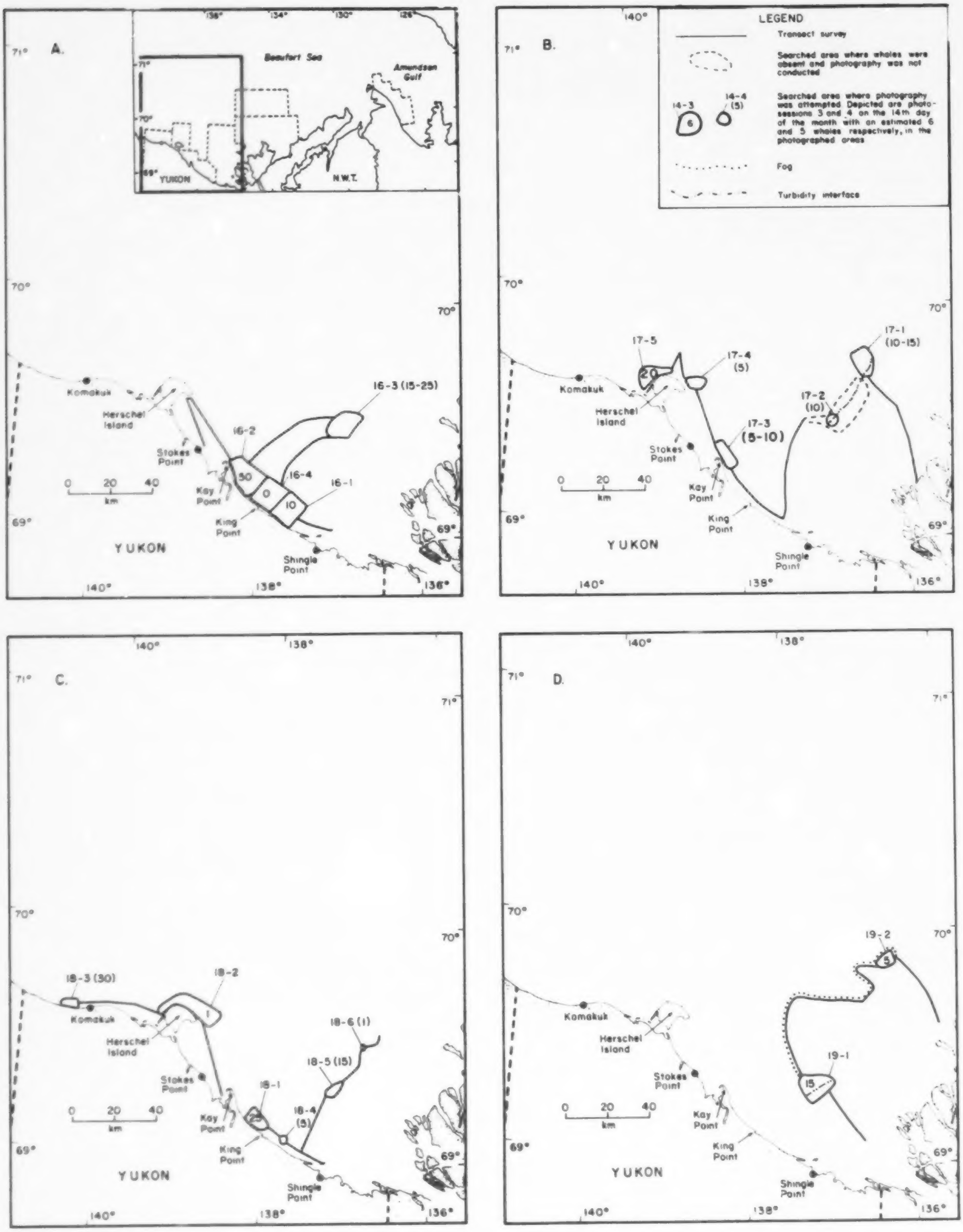
A.
Beaufort Sea
Amundsen Gulf
YUKON
N.W.T.
B.
LEGEND
Transect survey
Searched area where whales were absent and photography was not conducted
Searched area where photography was attempted. Depicted are photo-sessions 3 and 4 on the 14th day of the month with an estimated 6 and 5 whales respectively, in the photographed areas
14-3
6
14-4
(5)
Fog
Turbidity interface
C.
D.
Komakuk
Herschel Island
Stokes Point
Kay Point
King Point
Shingle Point
YUKON
0 20 40
km
16-1
16-2
16-3 (15-25)
16-4
30
0
10
17-1
(10-15)
17-2
(10)
17-3
(5-10)
17-4
(5)
17-5
20
18-1
18-2
18-3 (30)
18-4
(5)
18-5 (15)
18-6 (1)
19-1
15
19-2
5
71°
70°
69°
140°
138°
136°
134°
130°
126°

FIG. 18. Locations of aerial surveys and photographic sessions conducted on 16 August (A), 17 August (B), 18 August (C), and 19 August (D) 1984.

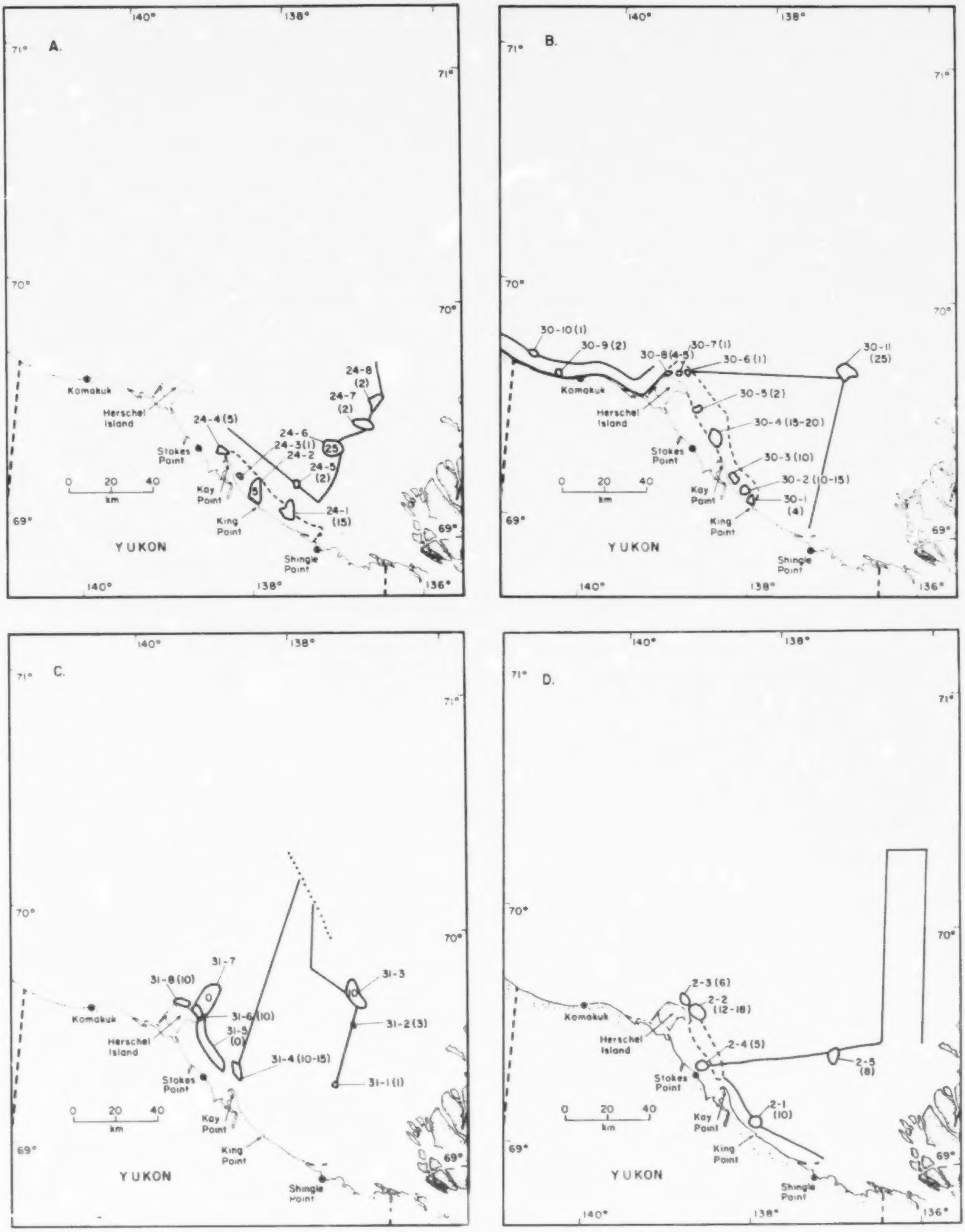
A.
140°
138°
71°
70°
69°
136°
Komakuk
Herschel Island
Stokes Point
Kay Point
King Point
Shingle Point
YUKON
0 20 40
km
24-8 (2)
24-7 (2)
24-6
24-3(1)
24-2
24-5 (2)
24-4 (5)
24-1 (15)
25
5
B.
30-10 (1)
30-9 (2)
30-8 (4-5)
30-7 (1)
30-6 (1)
30-11 (25)
30-5 (2)
30-4 (15-20)
30-3 (10)
30-2 (10-15)
30-1 (4)
C.
31-8 (10)
31-7
31-6 (10)
31-5 (0)
31-4 (10-15)
31-3
31-2 (3)
31-1 (1)
0
10
D.
2-3 (6)
2-2 (12-18)
2-4 (5)
2-5 (8)
2-1 (10)

FIG. 19. Locations of aerial surveys and photographic sessions conducted on 24 August (A), 30 August (B), 31 August (C), and 2 September (D) 1984.

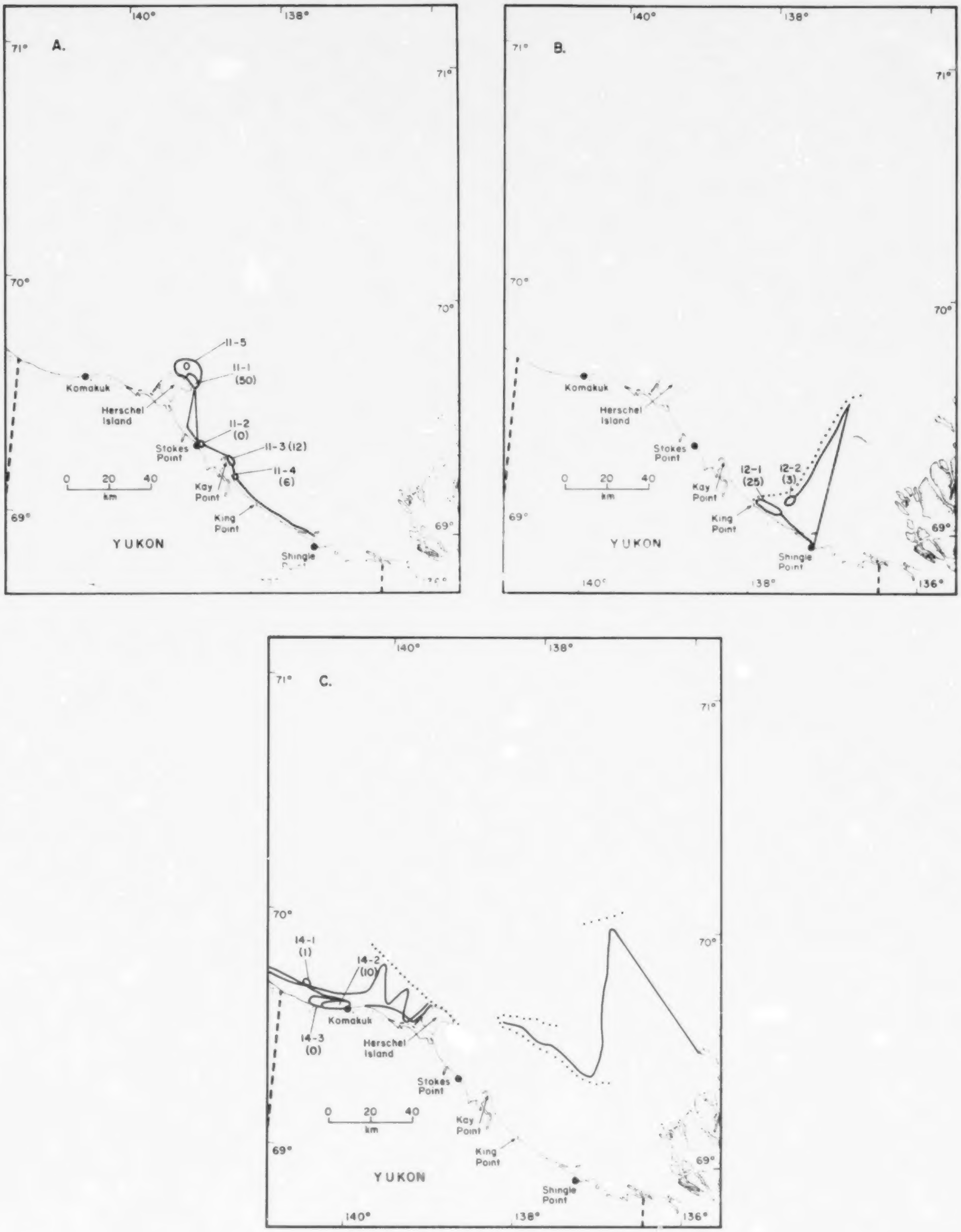
A.
B.
C.
140°
138°
136°
71°
70°
69°
11-5
11-1 (50)
11-2 (0)
11-3 (12)
11-4 (6)
12-1 (25)
12-2 (3)
14-1 (1)
14-2 (10)
14-3 (0)
Komakuk
Herschel Island
Stokes Point
Kay Point
King Point
Shingle Point
YUKON
0 20 40
km

FIG. 20. Locations of aerial surveys and photographic sessions conducted on 11 September (A), 12 September (B), and 14 September (C) 1984.

Distribution

On most days, we found bowheads in the Interface Zone; usually one group of 20-30 animals could be found (Table 8). However, the locations of the animals along the length of the interface were quite variable from day-to-day. Also the distribution with respect to the interface varied within any particular area. On some occasions the whales were present along the clearer

Table 8. Estimated numbers of whales, numbers of photographs of usable quality, and number of measured whales during each photographic session in the Interface Zone, 16 August-2 September 1984.

Photo Session	Estimated Number of Whales	Number of Grade A and B Photos	Number of Different Whales with Grade A and B Photos	Number of Different Whales with Grade A Photos	Number of Different Measured Whales*
16-3	20 (15-25)	39	31	17	28
17-1	13 (10-15)	17	12	2	8
17-2	10	1	1	0	1
18-5	15	7	7	0	3
18-6	1	1	1	0	0
19-1	15	1	1	0	1
19-2	5	1	1	0	0
24-6	25	33	31	2	10
24-7	2	0	0	0	0
24-8	2	-	-	-	-
30-11	25	27	25	10	12
31-1	1	0	0	0	1
31-2	3	0	0	0	0
31-3	10	4	4	0	0
2-5	8	8	7	0	0
Totals	155	139	121	31	64

* Grades 1-6 only.

side of the interface and on other occasions the whales were present in the very turbid water. Some of these animals were apparently feeding in clearer water below the turbid surface layer at the interface. This was indicated by clear water patches left by whales surfacing through the turbid layer.

Bowheads on the 'clear' water side of the interface were usually less concentrated near the plume edge than were groups on the turbid side. Groups of animals were often dispersed from the edge to a distance of several km to the west or northwest. Most of the animals recorded in the Interface Zone were in water that was 10-30 m deep.

Bowheads in the southwestern part of the Interface Zone were not close to much industrial activity. A seismic vessel operated to the east of these whales in late August (Fig. 5), and a clamshell and barges operated at the Sarpik artificial island (Fig. 3). However, these operations were in shallow water. Sonobuoys dropped near whales in the southwestern part of the Interface Zone showed that underwater noise from these sites did not reach the whales (Richardson et al. 1985b).

Bowheads that were farther to the northeast in the central part of the Interface Zone were exposed to more industrial activity. A **seismic vessel** operated just to the west for much of the mid- and late August period (Fig. 5). Some of its lines were within 10 km of whales along the interface. At 10 km range, the received level of seismic noise pulses was 158 dB re 1μPa--a high value (Richardson et al. 1985b). On one occasion (16 August) this seismic vessel came within 1 1/2 km of several whales during a disturbance experiment. **Helicopters** en route between Tuktoyaktuk and Herschel Island flew over the interface a few times each day (Fig. 4). They sometimes passed directly over groups of whales (e.g., on 13 August and 28 August; Richardson et al. 1985b and pers. comm.). Underwater noise from **dredges** constructing an artificial island at Minuk (Fig. 3), east of the interface, also reached whales 13 km away along the interface, at least on 30 and 31 August (Richardson et al. 1985b). The behavior of the bowheads exposed to these industrial activities was not noticeably different from normal, with the exception that bowheads did cease feeding and move away when the seismic vessel approached within a few kilometres (Richardson et al. 1985b).

Numbers

It is difficult to estimate the numbers of bowheads that used the Interface Zone in 1984. Too few systematic surveys were flown in this zone to derive numerical estimates (Harwood and Borstad 1985). A further complication is that there was apparently a very high turnover rate for individuals in this zone. Analyses of individual identifications from photographs (see later sections) indicated that few, if any, whales remained in the zone for extended periods. Animals photographed on one day were not the same as those photographed in the same general area on previous days.

A reasonable estimate is that about 50-100 bowheads were present in the Interface Zone at any one time but much larger numbers used the zone through the course of the study period.

Length Distribution

A total of 64 different whales were measured from samples on seven days; daily sample sizes ranged from one to 28 length measurements (Fig. 21). The mean length of the 64 whales was 10.4 m (Table 2). For the most part, whales in the Interface Zone were immature animals; only 3 of 64 (4.7%) were adults of greater than 13 m. Nine (14%) of the whales were less than 8.7 m and therefore classed as yearlings. If the more liberal interpretation of yearlings adapted by Nerini et al. (1984) is used, then 47% (30 of 64) were less than 10 m long and therefore possible yearlings.

The distribution of whale lengths was somewhat variable from day-to-day (Fig. 21). This may suggest that different groups were being photographed on different days. This indication confirms the suggestion that individual whales were not re-identified on days subsequent to their first identification.

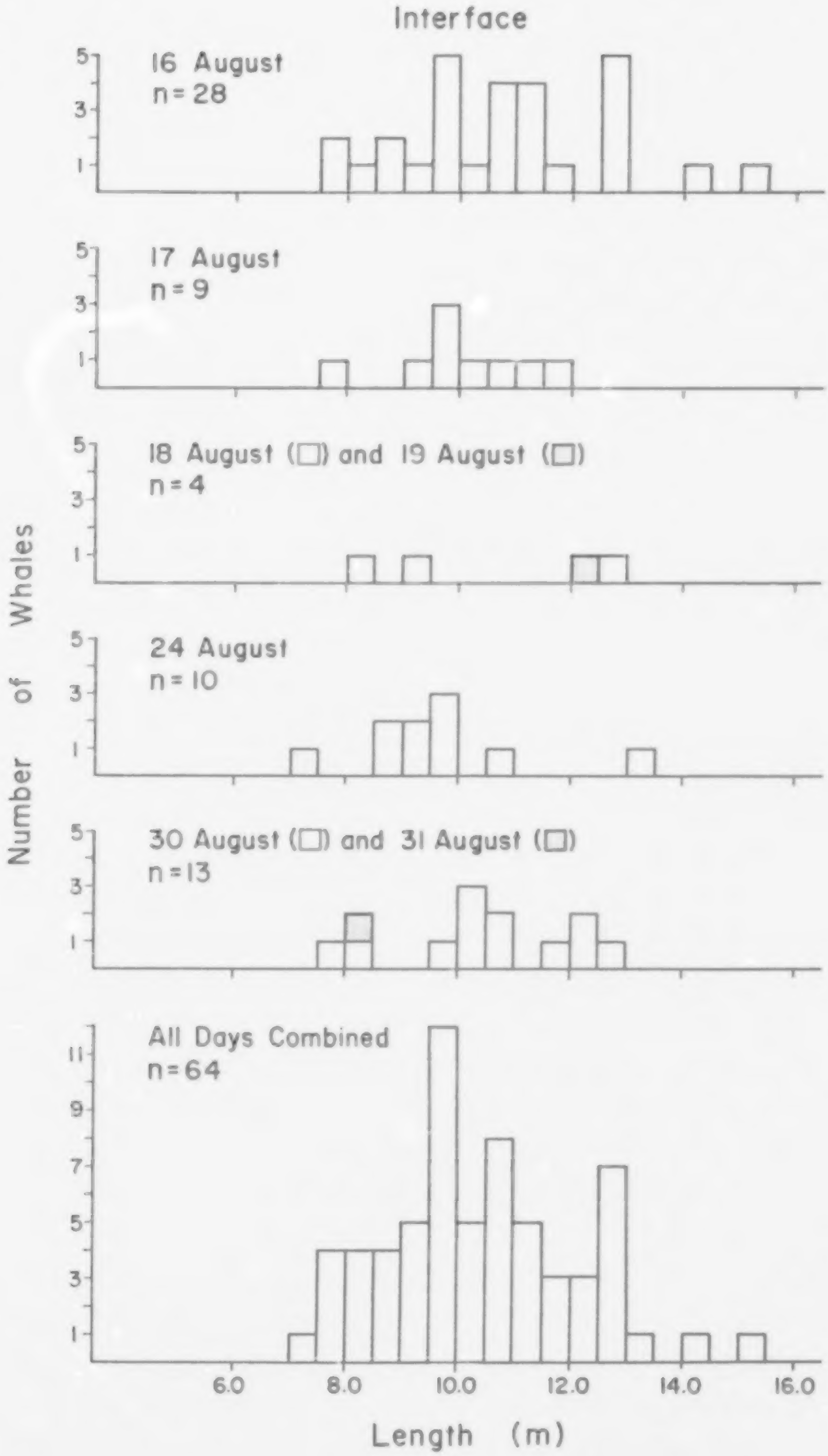

FIG. 21. Length-frequency distributions of bowhead whales photographed in the Interface Zone, 16-31 August 1984.

King Point Zone

Coverage

The combination of localized good weather conditions and large numbers of whales led to intensive aerial coverage of the King Point Zone (Table 1). The zone was sampled on 11 different days from 15 August to 12 September, including one period with coverage on four consecutive days (15-18 August). The extent of the coverage on each day is plotted in chronological order in Figs. 11, 18, 19, 12 and 20. On several of the days, more or less complete coverage of the entire zone was obtained using the 'aerial search' procedures.

Distribution

The distribution of bowheads in the King Point Zone was quite variable, even on successive days. Review of the distribution maps (Figs. 11, 12, 18, 19, 20) indicates that whales were most abundant in various locations along a NW-SE axis parallel to and within a few km of the coast. It was quite unusual for large numbers of animals to be present in the same locations on successive days with coverage. There was also some variation in the distance offshore from the coast to which concentrations extended. It would be tempting to conclude that groups of whales were moving about the zone in response to changing local conditions that affected the distribution of zooplankton concentrations. However, the situation was apparently more complicated because there seemed to be quite rapid turnover of whales within the King Point Zone (see later sections). Thus, similar-sized groups of whales seen in adjacent areas on successive days probably were not the result of local movements by the same group but rather they were probably different groups.

Most of the bowheads in the King Point Zone in 1984 were in waters less than 30 m deep.

The many whales near the Yukon coast in the King Point Zone were exposed to very little industrial activity (Fig. 3-5). Sonobuoys were dropped near whales in this area on several occasions, and these detected little or no industrial noise. However, bowheads in the western part of the zone, near Kay Point, were sometimes exposed to distant engine noise, probably from ships in the Herschel Basin area to the northwest (W.J. Richardson, pers. comm.). Also, groups of whales were exposed to underwater noise during five disturbance tests (boat, airgun and dredge noise playback) in this zone during mid-late August 1984 (Richardson et al. 1985b).

Numbers

The late August surveys of Harwood and Borstad (1985) were not able to obtain coverage in the eastern half of the King Point Zone; thus, their data cannot be used to derive population estimates for the zone. The second survey by these workers was conducted from 6 to 11 September along, and offshore from, the Yukon coast. Most of the animals that they saw were fairly close to the coast and would have been in our King Point, Herschel Island, or Komakuk zones. Harwood and Borstad (1985) estimated (with corrections) that 1000-1600 bowheads were present in their Yukon block. Thus, large numbers of whales were present along the Yukon coast, including the King Point Zone, in early to mid September. Our own results suggest that just as many bowheads were present in the King Point Zone in the last half of August as were present in the first half of September.

The detailed results and estimates for each photography session are summarized in Table 9.

Length Distribution

Overall, 108 different whales in King Point Zone were measured. The average length was only 9.7 m (s.d. ± 1.64), which was somewhat smaller than the 10.4 m average in the Interface Zone. Usable measurements were obtained on 11 days with the daily sample size ranging from one to 26 different whales (Fig. 22).

Table 9. Estimated numbers of whales, numbers of photographs of usable quality, and number of measured whales during each photographic session in the King Point Zone, 15 August-12 September 1984.

Photo Session	Estimated Number of Whales	Number of Grade A and B Photos	Number of Different Whales with Grade A and B Photos	Number of Different Whales with Grade A Photos	Number of Different Measured Whales*
15-1	45 (40-50)	27	27	11	16
16-1	10	0	0	0	0
16-2	50	51	45	15	18
16-4	0	-	-	-	-
17-3	8 (5-10)	6	3	0	2
18-1	25	34	26	4	15
18-4	5	2	2	0	0
24-1	15	13	13	2	4
24-2	5	3	3	0	2
24-3	1	1	1	0	0
24-4	5	5	4	1	1
24-5	2	0	0	0	0
27-1	0	-	-	-	-
27-2	3	0	0	0	0
27-3	10	22	17	1	2
27-4	18 (15-20)	22	17	2	7
30-1	4	4	4	0	1
30-2	13 (10-15)	11	11	1	2
30-3	10	11	10	1	5
30-4	18 (15-20)	29	23	14	18
31-4	13 (10-15)	10	7	1	6
31-5	0	-	-	-	-
2-1	10	2	2	0	1
2-4	5	12	5	1	5
11-2	0	-	-	-	-
11-3	12	8	8	0	3
11-4	6	7	7	0	-
12-1	25	14	11	1	1
12-2	3	-	-	-	0
Totals	321	294	246	55**	109***

* Grades 1-6 only.

** Representing 54 different whales (one whale with grade A photographs was photographed on two days).

*** Representing 108 different whales (one whale was measured on two days).

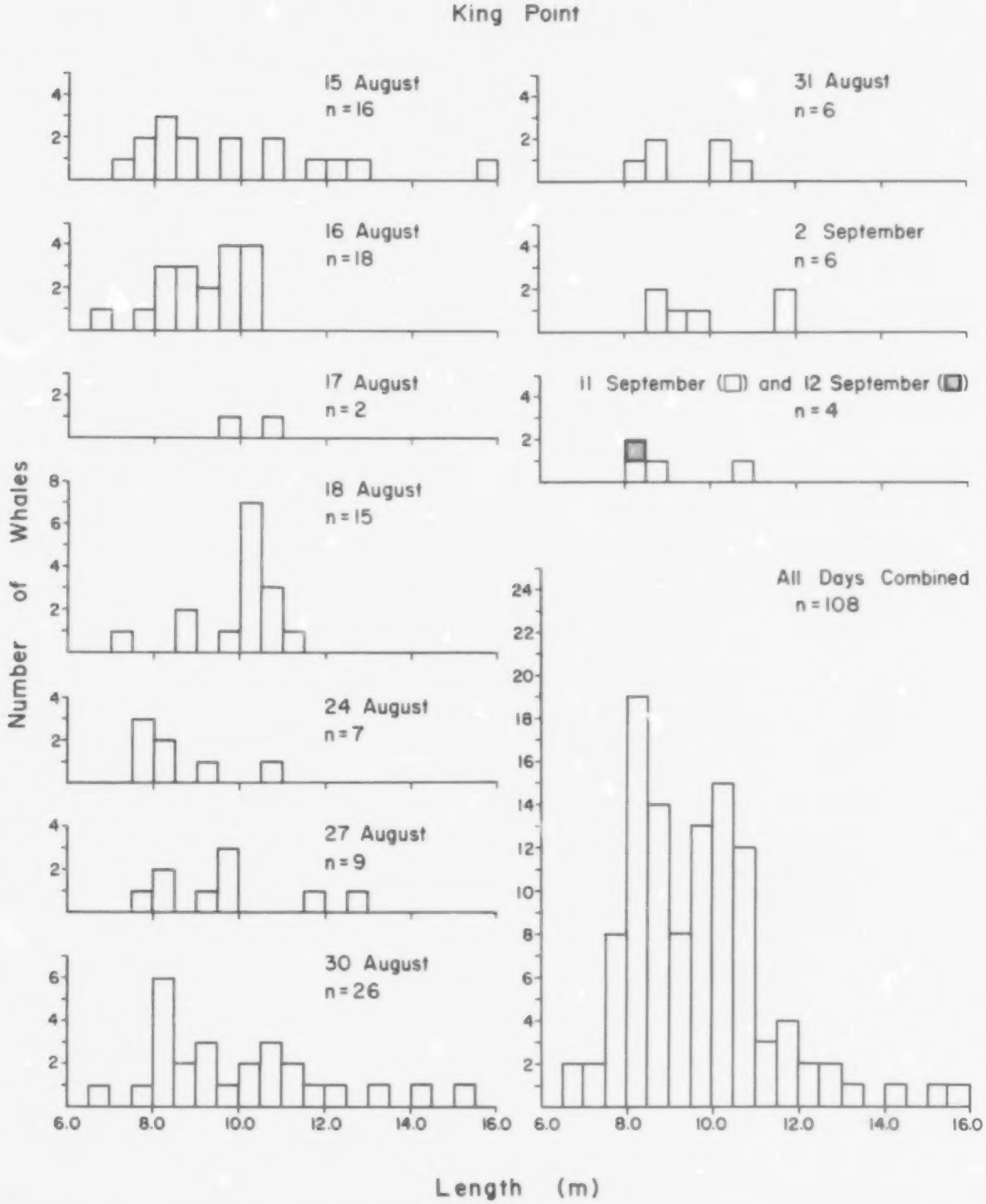

FIG. 22. Length-frequency distributions of bowhead whales photographed in the King Point Zone, 15 August-12 September 1984. Combined total excludes second measurements of whales photographed on more than one day.

Examination of the length distribution on each day indicates differences between days. For example, 38% of the whales on 15 August were longer than 10.5 m but these animals were not recorded at all on the next day. By 18 August, there was an apparent influx of 10-11 m whales. Similar day-to-day changes occurred throughout the study period (Fig. 22). These patterns support the contention that there was a high turnover of whales from day-to-day in the King Point Zone in 1984.

Only 4% (4 of 108) of the measured whales were adult (over 13 m) animals. Three of the four were found on 30 August, but no animals over 13 m long were measured on adjacent dates (27 and 31 August). One of the three adults found on 30 August was accompanied by a calf. Three other unaccompanied animals were between 7.0 and 7.5 m--one each on 15, 16 and 18 August. These were potential calves, although they may have been small yearlings. On only one of these three days (15 August) was an adult confirmed to be present in the group with the potential calf. Thirty (28%) of the whales measured in the King Point Zone were yearlings according to the conservative criterion (7.6 to 8.7 m) of Davis et al. (1983). However, fully 62 (57%) were yearlings according to the more liberal criterion (7.6 to 10 m) of Nerini et al. (1984).

Herschel Island Zone

Considerable seismic exploration occurred in the northern part of the Herschel Island Zone in early August (before this study) and in early September (Fig. 5). Aside from seismic exploration, most of the Herschel Island Zone was relatively free of industrial activity. However, the southeastern corner of the zone contained the marine base of Gulf Canada Resources at and near Pauline Cove. Underwater noise from the ships there was detectable, at least faintly, as far to the east and southeast as Kay Point (Greene 1985; Richardson et al. 1985d).

Coverage

Aerial coverage in the Herschel Island Zone was obtained on eight different days (Table 1), although the coverage on 16 August was minimal and no whales were found on 14 September. The locations of the aerial coverage are shown in chronological order in Figs. 18, 19 and 20.

Throughout most of the study, heavy pack ice was present in the northern half of this zone. Thus, our coverage did not include the north half of the Herschel Island Zone. The most intensive coverage was of waters off the west, north and northeast shores of Herschel Island, and of the waters on a direct line from northeast Herschel Island toward Kay Point.

Distribution and Numbers

The locations and numbers of bowheads near Herschel Island were quite variable from day-to-day. For example, the numbers estimated to be present along the west, north and northeast coasts varied as follows (Table 10):

17 August - 25 whales
18 August - 1 whale
30 August - 4 whales
31 August - 20 whales
2 September - 27 whales
11 September - 62 whales

During photography sessions, we often had the impression that these animals were moving through the area rather than lingering and feeding in the area.

Most of the surveyed waters in the Herschel Island Zone were less than 50 m deep and, as a result, whale sightings were in these relatively shallow waters. The deeper waters of nearby Herschel canyon were only briefly surveyed and whales were not found there. Results from other simultaneous studies showed that there were few bowheads in the deeper waters relative to the rather high numbers close to shore (Fig. 7-9).

Table 10. Estimated numbers of whales, numbers of photographs of usable quality, and number of measured whales during each photographic session in the Herschel Island Zone, 17 August-11 September 1984.

Photo Session	Estimated Number of Whales	Number of Grade A and B Photos	Number of Different Whales with Grade A and B Photos	Number of Different Whales with Grade A Photos	Number of Different Measured Whales*
17-4	5	8	6	3	5
17-5	20	18	14	5	11
18-2	1	1	1	0	0
30-5	2	2	2	1	2
30-6	1	-	-	-	-
30-7	1	1	1	1	1
30-8	5 (4-5)	3	3	0	2
31-6	10	7	6	0	3
31-7	0		-	-	-
31-8	10	16	13	2	9
2-2	15 (12-18)	23	18	2	11
2-3	6	9	9	1	5
11-1	50	69	62	4	18
11-5	0	-	-	-	-
Totals	126	157	135	19	67

* Grades 1-6 only.

Reliable estimates of numbers of whales in the Herschel Zone are not available. As shown earlier, the numbers were highly variable from day to day. Peak numbers were apparently present on 11 September when we estimated 50 whales in area 11-1 but later found that we had photographs of 62 different whales from only 69 photographs. In addition, only a relatively small proportion of the Herschel Island Zone was covered on 11 September (Fig. 20A). Clearly, the estimate of 62 whales should be considered a bare minimum.

Length Distribution

A total of 67 length measurements were obtained over five days in the Herschel Island Zone. The mean length of the 67 whales was 10.3 m (s.d. ± 1.67). The daily samples ranged from 5 to 18 measurements. Within the limits of small sample sizes, the length distributions on the five days were not too dissimilar (Fig. 23). The modal (n = 15) size category was 10-10.5 m.

Yearlings represented 18% (12 of 67) of the sample using the criterion (7.6-8.7 m) of Davis et al. (1983) or 34% (23 of 67) using the criterion (7.6-10 m) of Nerini et al. (1984).

Single adult (over 13 m) animals were measured on each of three days. Thus, only 4% of the measured sample were adults. None of the adults was accompanied by a calf. Two small animals (7.1 and 7.3 m) were potentially young of the year based on their length but both measurements were of low quality (grades 5 and 6). Based on morphological characteristics (see later section), the 7.3 m animal was almost certainly a yearling and the 7.1 m whale could not be classified. The former animal was associated with a 7.8 m whale, and the 7.1 m animal was associated with three small animals (8.0, 10.2, 11.1 m).

Komakuk Zone

Coverage

The Komakuk Zone was selected as an undisturbed control area since it was exposed to minimal ship and helicopter traffic in 1984, and no drillsites or construction sites were present (Fig. 3, 4). There was high-energy seismic exploration in this zone in early August and early September, but not in mid-late August (Fig. 5). We obtained aerial coverage of this zone on three days. This coverage is plotted in Fig. 18C (18 August), Fig. 19B (30 August), and Fig. 20C (14 September). The first sighting of whales near Komakuk had been on 13 August (D. Rugh, NMFS, pers. comm.; Fig. 7).

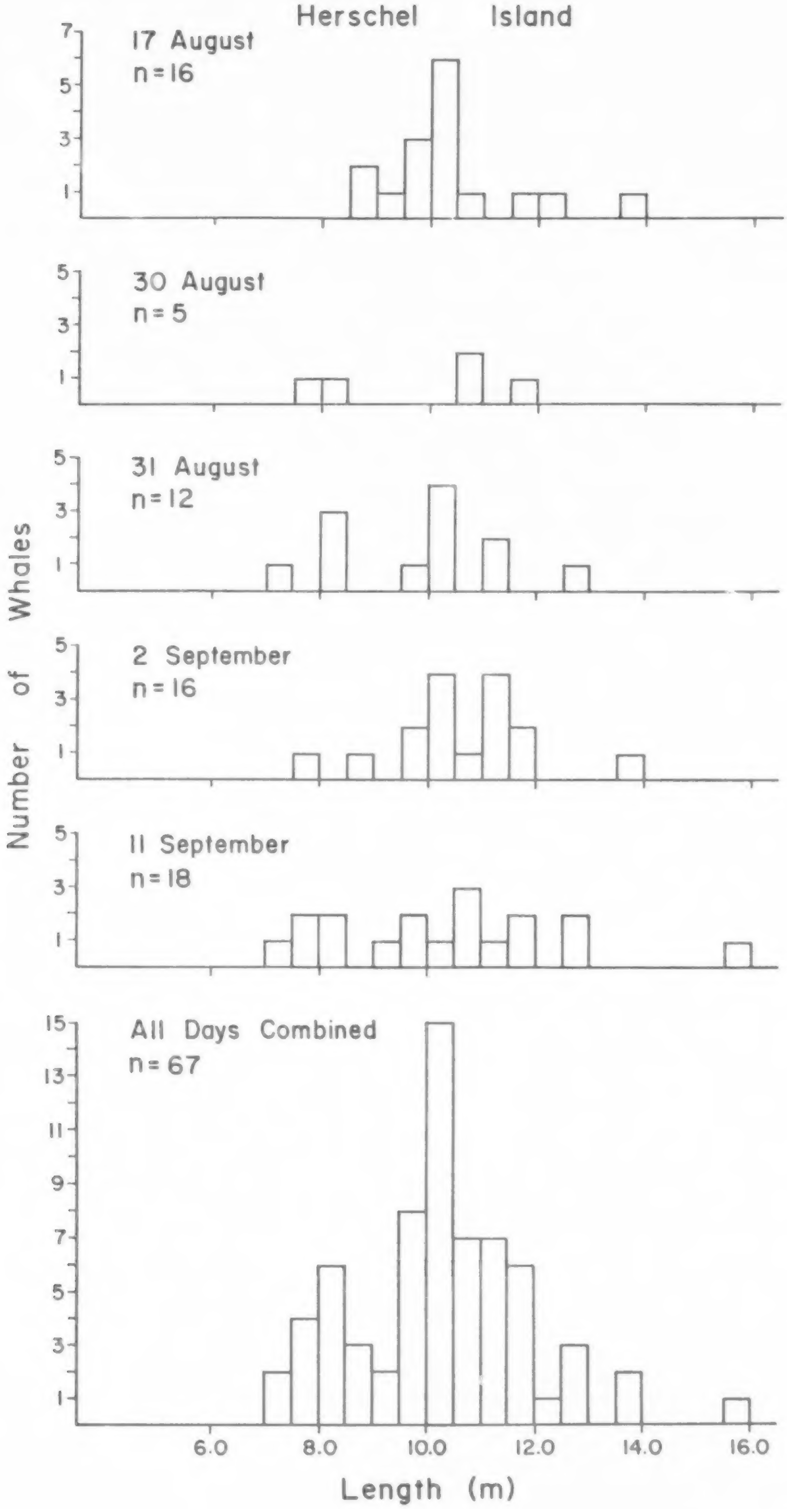

FIG. 23. Length-frequency distributions of bowhead whales photographed in the Herschel Island Zone, 17 August-11 September 1984.

Distribution and Numbers

Our coverage in the Komakuk Zone was not intensive and not frequent. Thus, quantitative estimates of numbers were not obtained. The numbers present were apparently variable from day-to-day. Numerous whales were present on 18 August and 14 September, but relatively small numbers were present on 30 August (Table 11) in spite of the most intensive coverage being obtained on that day (Fig. 19).

Only two major groups of whales were seen during our three days of surveys. The groups were both found immediately west of the Komakuk DEW site: 30 whales on 18 August and 10 whales on 14 September. None were present in this area on 30 August. The group of 30 bowheads found on 18 August was very close to shore in shallow water less than 15 m deep. Animals were present within 50 m of shore on occasion during our photography session. The group on 14 September was more dispersed than the group in August but it was also in shallow water less than 20 m deep.

Table 11. Estimated numbers of whales, numbers of photographs of usable quality, and number of measured whales during each photographic session in the Komakuk Zone, 18 August-14 September 1984.

Photo Session	Estimated Number of Whales	Number of Grade A and B Photos	Number of Different Whales with Grade A and B Photos	Number of Different Whales with Grade A Photos	Number of Different Measured Whales*
18-3	30	34	29	7	15
30-9	2	3	3	0	2
30-10	1	0	0	0	0
14-1	1	0	0	0	-
14-2	10	24	12	1	10
14-3	0	-	-	-	-
Totals	44	61	44	8	27

* Grades 1-6 only.

Length Distribution

A total of 27 measurements was obtained over three days in the Komakuk Zone. Daily sample sizes ranged from 2 to 15 measurements (Fig. 24). The mean length of the 27 measured animals was only 9.5 m (s.d. ± 1.36).

Only one (4%) adult (over 13 m) was measured at Komakuk; it was a 13.8 m whale accompanied by a 5.8 m calf. Only one other animal (11.5 m) was longer than 11 m. Three (11%) whales were classed as yearlings by the criterion (7.6-8.7 m) of Davis et al. (1983), whereas fully 20 (74%) were yearlings according to the criterion (7.6-10 m) of Nerini et al. (1984).

Resightings of Whales

Each printed whale image was assigned a re-identification grade based on photo quality and whale markings (see Methods). Grade B whales are those that may be re-identified on the same day or within a few days of the original photograph. Grade A images represent high quality photographs of well marked whales; similar quality photographs later in the season or in future years should allow re-identification of the whale. Re-identifications can be used to evaluate how long individuals remain in the same locality and how far and fast whales move between areas. Comparisons of residence times and movement rates of whales exposed to industrial disturbance and whales in undisturbed control areas can then be made.

Within-Session Re-identifications

During single photographic sessions in a particular area, we inevitably photographed some whales more than once if much time was spent in that area. Only one photographic session was conducted in a particular area on one day. Thus, references in this report to 'within-session' and 'within-day' resightings are synonymous.

A total of 942 Grade A and B images were printed in the present study. This total contained 201 within session re-identifications or 21.3% of the overall sample. Of the 741 different whales photographed, the highest grade

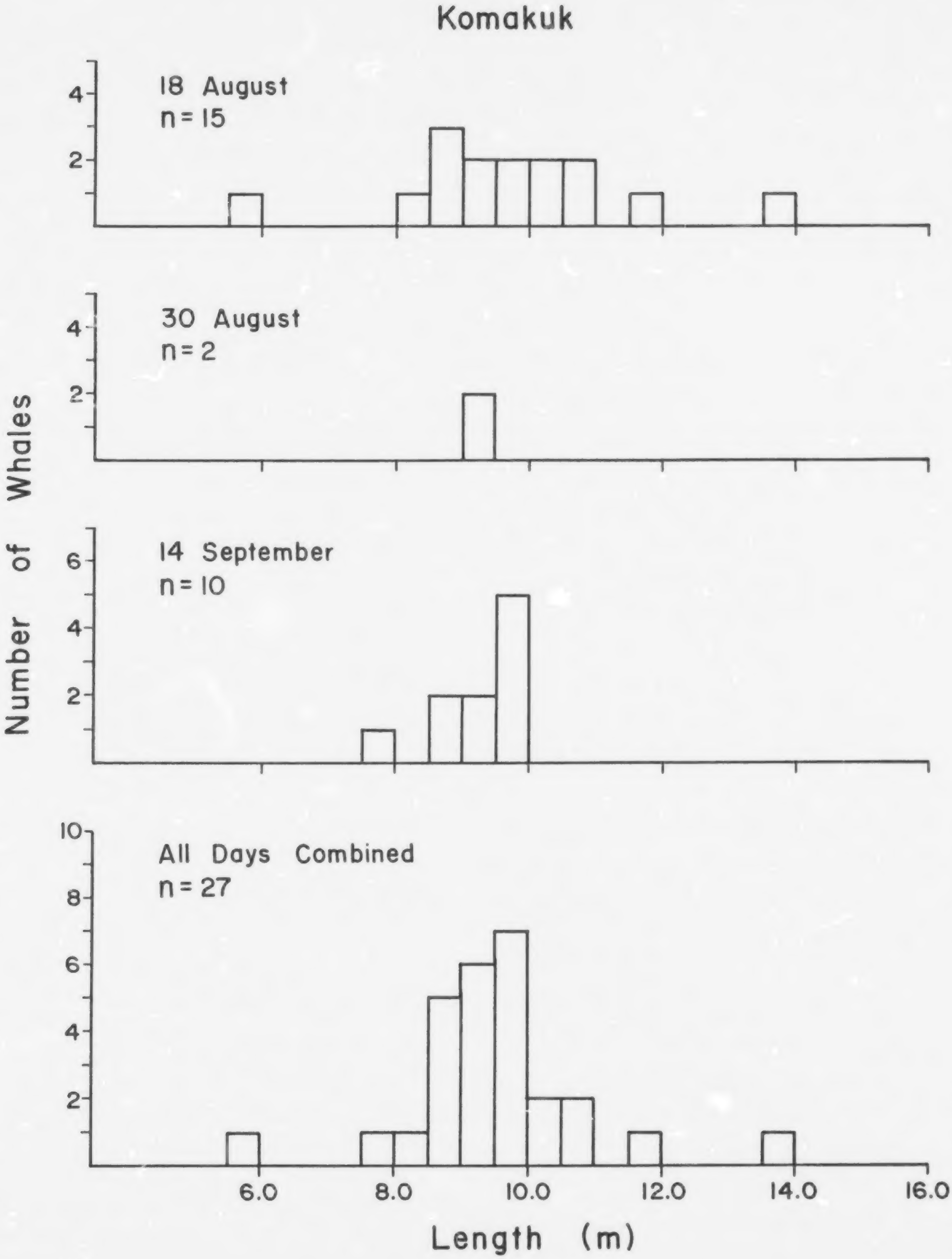

FIG. 24. Length-frequency distributions of bowhead whales photographed in the Komakuk Zone, 18 August-14 September 1984.

of photograph was Grade A for 25.5% (189 of 741) and Grade B for 74.5% (552 of 741) of the whales (Table 12).

Between-Day Re-identifications

During the 1984 study, a total of only seven bowheads were re-identified on more than one day. The number of resightings was surprisingly small relative to our 1982 study when 14 inter-day resightings were made even though the number of photos was lower (402 different whales) and attempts were made to avoid rephotographing whales in 1982. The between-day resightings in each year are listed in Table 13. The 1984 resightings can be divided into two groups (Franklin Bay and Yukon coast) with somewhat different characteristics.

Table 12. Numbers and re-identification grades of bowhead whale images from various geographic zones, 14 August-12 September 1984.

Zone	No. of Grade A + B Images	No. of Different Whales	No. of Different Grade A Whales	Grade A as % of No. of Diff. Whales	No. of Days with >18 Grade A + B Images
Franklin Bay	186	141	52	36.9	3
North Industrial	77	34	23	67.6	1
South Industrial	28	20	1	5.0	1
Yukon Coast					
Interface	139	121	31	25.6	4
King Point	294	246	55	22.4	6
Herschel Island	157	135	19	14.1	4
Komakuk	61	44	8	18.2	2
Totals	942	741	189	25.5	

Table 13. Resightings of bowhead whales on different days during the 12 August-5 September 1982 (Davis et al. 1983) and 14 August-14 September 1984 periods (this study).

	First Photographed			First Resighting			Time Between Sightings (h)	Minimum Distance Travelled (km)	Rate of Net Movement (km/h)	Second Resighting			Time Between Sightings (h)	Distance Travelled (km)	Rate of Net Movement (km/h)
	Date	Lat.	Long.	Date	Lat.	Long.				Date	Lat.	Long.			
1982															
1	12 Aug	-	-	16 Aug	69°46.9'	138°47.5'	93	-							
2	16 Aug	69°50.1'	138°53.7'	18 Aug	69°44.2'	138°42.6'	44	13	0.29						
3	16 Aug	69°51.2'	138°55.7'	18 Aug	69°42.7'	138°39.2'	44	17	0.39						
4	16 Aug	69°43.4'	138°41.1'	18 Aug	69°41.9'	138°37.2'	46	4	0.09						
5	16 Aug	69°47.3'	138°48.9'	18 Aug	69°40.7'	138°35.4'	46	13	0.28						
6	16 Aug	69°48.2'	138°48.9'	16 Aug	69°45.8'	138°47.1'	44	5	0.11						
7	16 Aug	69°47.3'	138°48.0'	18 Aug	69°45.8'	138°47.7'	45	3	0.07						
8	16 Aug	69°45.0'	138°43.3'	18 Aug	69°42.1'	138°36.5'	46	7	0.15						
9	16 Aug	69°43.8'	138°41.6'	18 Aug	69°45.9'	138°47.3'	42	5	0.12						
10	16 Aug	69°46.0'	138°45.3'	18 Aug	69°41.5'	138°36.5'	46	10	0.22						
11	16 Aug	69°48.3'	138°50.3'	4 Sept	70°08.1'	139°06.1'	458	38	0.08						
12	16 Aug	69°53.3'	138°58.9'	4 Sept	70°35.9'	138°52.0'	457	79	0.17[1]						
13	18 Aug	69°44.9'	138°44.9'	23 Aug	70°39.0'	136°40.0'	121	154	1.27	5 Sept	69°39.0'	138°16.4'	311	147	0.47
14	18 Aug	69°44.9'	138°46.0'	24 Aug	69°40.3'	138°36.3'	145	9	0.06						
15	4 Sept	69°36.7'	138°12.0'	5 Sept	69°39.2'	138°01.4'	22	8	0.36						
1984 Yukon Coast															
	16 Aug	69°15.0'	138°12.0'	18 Aug	69°37.7'	140°25.4'	50	120	2.40						
	17 Aug	69°35.2'	138°40.9'	18 Aug	69°08.4'	137°59.3'	20	57	2.85						
	30 Aug	69°13.1'	138°15.2'	2 Sep	69°22.4'	138°42.3'	75	26	0.35						
Franklin Bay															
	23 Aug	69°58.2'	126°17.1'	1 Sep	69°51.9'	126°31.6'	211	15	0.07						
	23 Aug	69°56.9'	126°19.8'	6 Sep	70°34.8'	127°18.4'	327	82	0.25						
	23 Aug	70°42.0'	127°39.4'	6 Sep	70°34.0'	127°24.6'	325	16	0.05						
	1 Sep	69°58.5'	126°10.4'	6 Sep	69°59.5'	126°13.6'	117	3	0.02						

---

[1] 1982 inter-day resighting not recognized or reported in Davis et al. 1983.

The four resightings in Franklin Bay involved relatively large animals; the average length was 14.1 m with a range of 13.7 to 14.8 m. Thus, all of the resighted whales were potentially breeding adults. On the other hand, the three inter-day resightings along the Yukon coast involved small animals averaging 9.7 m in length with a range of 8.6 to 11.8 m. All three were small subadult animals.

The small size and relatively unmarked condition of whales along the Yukon Coast could have made it relatively difficult to recognize inter-day repeat photographs of these whales. However, we do not believe that this accounts for the very low number of resightings found in that area. In 1985, working with a similar sample size (822 A and B images of 652 different whales compared to 651 A and B images of 546 different whales in 1984) we recognized 27 inter-day resightings of 24 different whales in the same area along the Yukon coast (Davis et al. 1986). These 27 resightings included many small whales. Thus, we do not believe that the low number of inter-day resightings along the Yukon coast in 1984 can be explained by an inability to recognize resightings of small whales. In fact, five of the whales photographed along the Yukon coast in 1984 were rephotographed in 1985 (Richardson et al. 1986; Davis et al., in prep.). Three of these whales were less than 10 m in length. Clearly, if we were able to recognize these individuals when they were photographed in a different year we could recognize them on different days within the same season. Thus, the low resighting rate along the Yukon Coast is apparently the result of a high turnover of whales in that area rather than an inability to recognize inter-day resightings.

The movement patterns of the two groups of resightings were also very different. The time between resightings in Franklin Bay extended from the minimum possible 4.9 days (117 h) to the maximum possible 13.6 days (327 h; Table 13). Along the Yukon coast, the maximum time between resightings was only 3.1 days (75 h) even though there were many opportunities for longer periods between resightings (Table 1).

The locations of the seven inter-day resightings are mapped in Fig. 25 for Franklin Bay and Fig. 26 for the Yukon coast. All four whales that were resighted in Franklin Bay had been first sighted in that same zone. Three of the four individuals moved remarkably little during this period; only one of the four had moved from one of the two main sighting locations to the other (Horton River to Cape Bathurst; Fig. 25, Table 13). To evaluate the distance between resightings it is necessary to standardize the figures by the amount of time between the resightings. This is done by examining the data for rate of movement. The weighted average rate of movement was 0.12 km/h based on data in Table 13. In contrast, the resighted whales along the Yukon coast tended to move farther and to move at faster rates (Fig. 26, Table 13). The weighted average rate of movement along the Yukon coast was 1.40 km/h--an order of magnitude greater than in Franklin Bay.

It is possible that the differences in movement patterns in Franklin Bay and along the Yukon coast were related to the age (= length) of the whales. Perhaps the older, adult whales normally tend to be more sedentary than subadults. To examine this question, we plotted the average rate of movement between resightings against the length of the whale for the 15 between-day resightings obtained in 1982 (Fig. 27). There was no apparent relationship between rate of movement and whale age in 1982. Thus, the differences in patterns in 1984 may not be solely due to the age of the animals.

Rate of Re-identifications

In addition to the differences in whale length, time between sightings, and rates of movement for whales in Franklin Bay and along the Yukon coast, there was an indication that the rate of re-identification was higher in Franklin Bay. A total of 52 different Grade A whales were photographed in Franklin Bay (Table 12). Of these, four (7.8%) were resighted. Only one (0.9%) of the 113 Grade A whales along the Yukon coast was re-identified. Here we consider the Yukon coast to include the Komakuk, Herschel Island, King Point and Interface zones. The other two resightings in this area involved short-term sightings of Grade B whales. The difference in resighting rate for Grade A animals in Franklin Bay and along the Yukon coast was statistically significant ($\chi^2 = 5.62$; df = 1; $P<0.025$).

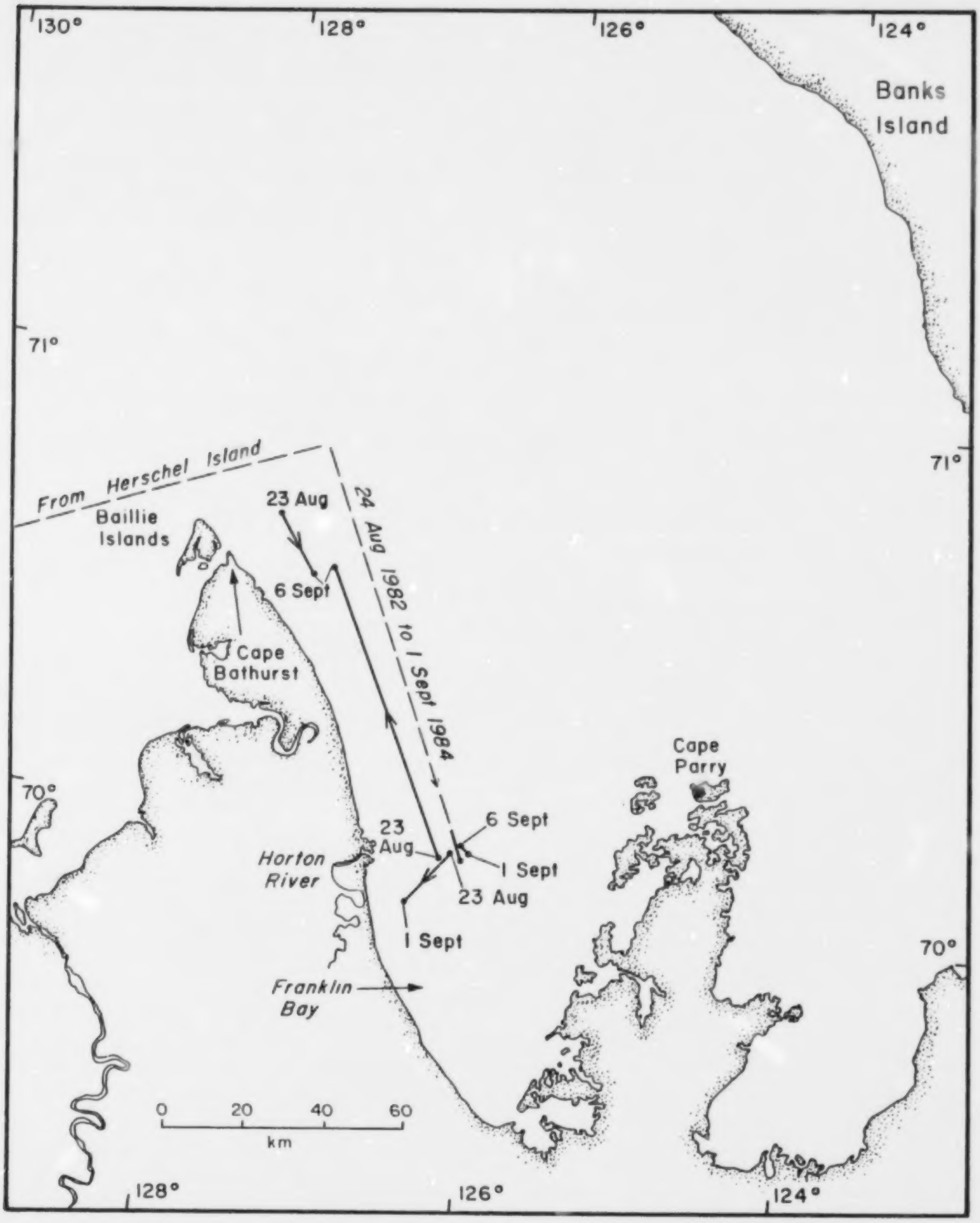
130°
128°
126°
124°
Banks Island
71°
71°
From Herschel Island
24 Aug 1982 to 1 Sept 1984
23 Aug
6 Sept
Baillie Islands
Cape Bathurst
Cape Parry
70°
23 Aug
6 Sept
1 Sept
23 Aug
1 Sept
Horton River
Franklin Bay
70°
0
20
40
60
km
128°
126°
124°

FIG. 25. Locations in Franklin Bay of between-day resightings in 1984 and between-year resightings for 1982 and 1984.

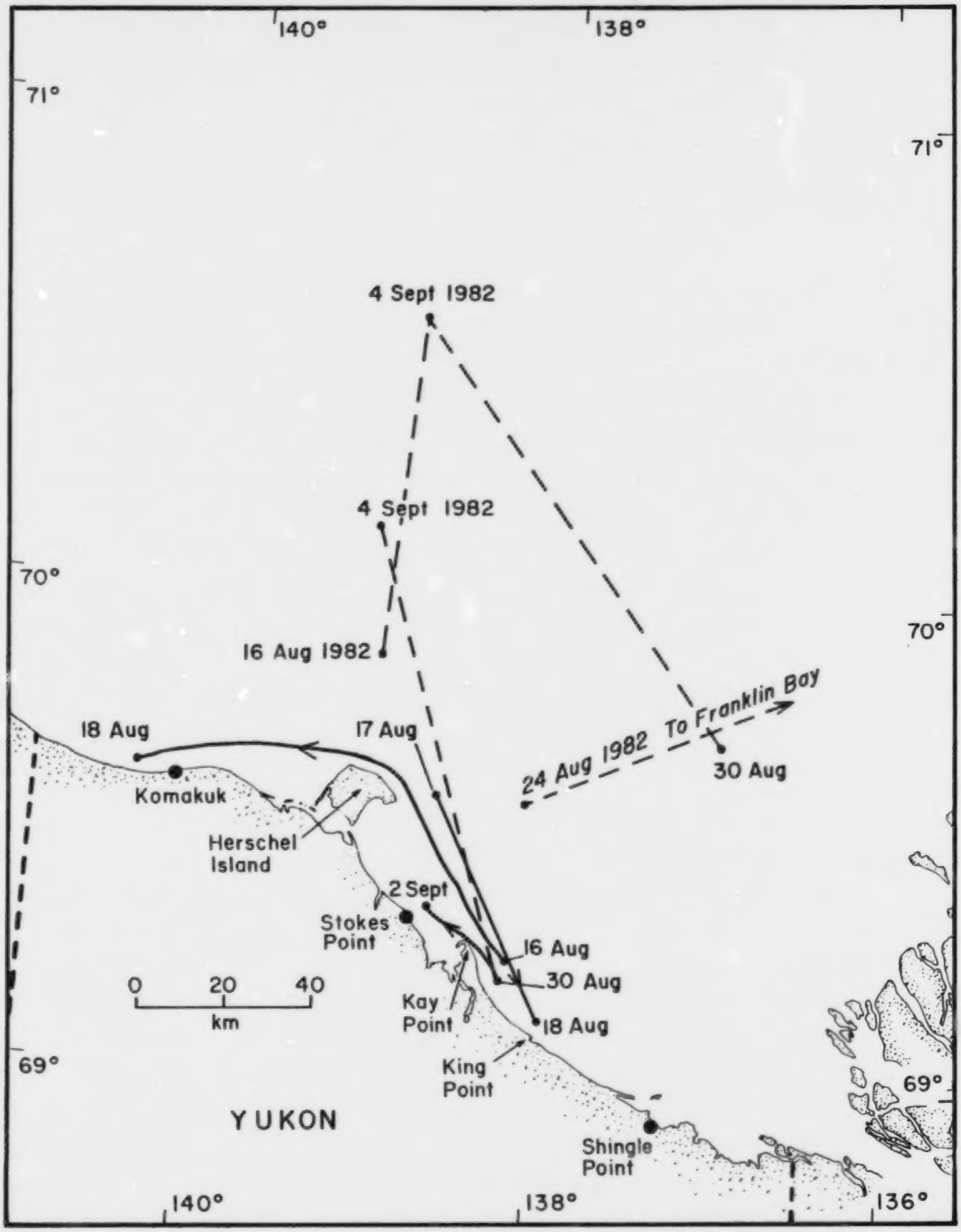
140°
138°
71°
71°
4 Sept 1982
4 Sept 1982
70°
70°
16 Aug 1982
24 Aug 1982 To Franklin Bay
30 Aug
18 Aug
17 Aug
Komakuk
Herschel Island
2 Sept
Stokes Point
16 Aug
30 Aug
18 Aug
0 20 40
km
Kay Point
King Point
69°
69°
YUKON
Shingle Point
140°
138°
136°

FIG. 26. Locations along the Yukon coast of between-day resightings in 1984 and between-year resightings for 1982 and 1984.

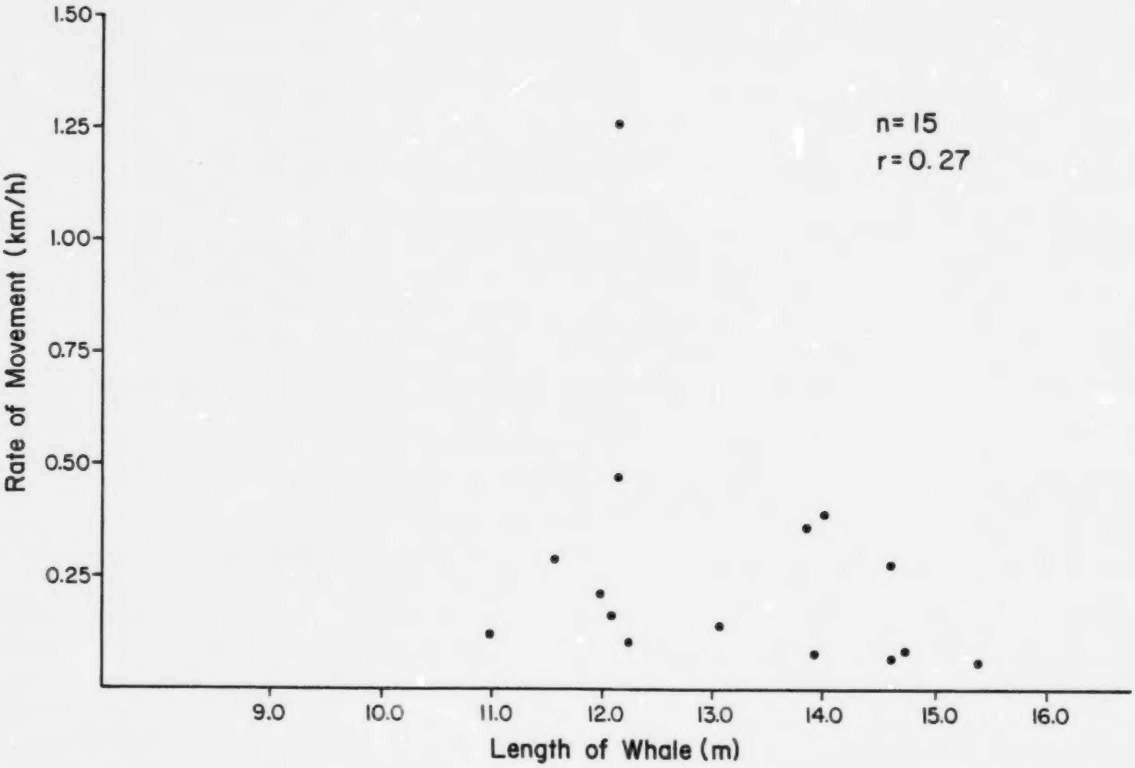

FIG. 27. Imputed net rate of movement for between day resightings of bowheads as a function of whale length, 12 August-5 September 1982.

When the sample is expanded to include short-term (1-2 day) resightings, the resighting rate in Franklin Bay is still higher even though this approach is biased against Franklin Bay because short-term re-identifications were not possible there. In Franklin Bay, four (2.8%) of 141 Grade A and B whales were resighted, whereas along the Yukon coast only three (0.5%) of 651 Grade A and B whales were resighted (Table 12). Again, this difference is statistically significant ($\chi^2 = 7.47$; df = 1; $P<0.01$). Thus, bowheads were more likely to remain and be re-photographed in the control area (Franklin Bay) than in the Yukon coast area.

Individual Movements

The four whales that were re-identified in Franklin Bay were resighted five, nine and 14 (2 cases) days after first being photographed (Table 13). Two of the animals remained in the same general area off the mouth of the Horton River and a third was quite sedentary off northeast Cape Bathurst (Fig. 25). However, there was some interchange among whales in Franklin Bay. The group photographed in area 6-1 (Fig. 16) off northeast Cape Bathurst on 6 September contained two individuals that had also been photographed on 23 August. On 23 August one of the whales was 82 km south of area 6-1 while the other was 16 km to the northwest. Thus, the two animals in area 6-1 on 6 September were about 100 km apart 14 days earlier.

It is difficult to discern any pattern in the three resightings along the Yukon coast (Fig. 26, Table 13). The small (8.6 m) individual first seen east of Kay Point on 16 August travelled at least 120 km WNW to an area along the coast about 10 km west of Komakuk on 18 August. At approximately the same time, an 8.6 m individual moved 57 km in 20 hours from an area east of Herschel Island SSE to King Point (Fig. 26). Thus, we have two relatively long distance movements at the same time but in essentially opposite directions. The third resighting along the Yukon coast was the only one of the three that did not involve movement between study zones. It was an 11.7 m whale that moved 26 km to the WNW off Kay Point within the King Point Zone.

Between-Year Resightings

Three of the 186 Grade A whales photographed in 1984 had also been photographed in 1982 (Table 14). The first resighting in Table 14 involved a whale photographed on two days in 1982 and on one day in 1984. [This 1982 inter-day resighting was not recognized or reported in Davis et al. (1983). Recognition of this additional inter-day and an additional same-day resighting reduced the number of different grade A whales in 1982 to 204.] On 16 August 1982 this individual was photographed twice in a large group (250+) of bowheads 25 km north of Herschel Island. In total, 106 length measurements ranging from 6.0 to 16.5 m were obtained from this group (see Davis et al. 1983, p. 54). This group included adults, calves, and sub-adults. On 4 September this individual was photographed 110 km north of

Table 14. Details of two between-year photographic re-identifications of bowhead whales.

Photo Number	Date	Time (MDT)	Position Lat (N)	Position Long (W)	Re-ident. Grade	Length (m)	Measurement Grade
82-06-05	16 Aug 1982	16:37	69°53.3'	138°58.9'	A	–	–
82-09-07	16 Aug 1982	17:21	69°51.5'	138°56.1'	A	12.1	2
82-57-03	4 Sep 1982	17:10	70°35.9'	138°52.0'	A	–	–
84-33-01	30 Aug 1984	19:46	69°42.5'	136°56.3'	A	12.6	4
82-40-03	24 Aug 1982	11:31	69°35.2'	138°07.4'	A	12.4	4
82-40-04	24 Aug 1982	11:33	69°34.9'	138°07.5'	A	12.1	4
82-40-05	24 Aug 1982	11:34	69°35.2'	138°07.5'	A	–*	–
84-39-13	1 Sep 1984	19:33	69°58.4'	126°09.1'	A	12.5	6
82-59-09#1	4 Sep 1982	18:46	70°08.5'	139°06.2'	A	11.8	3
84-30-09	30 Aug 1984	12:15	69°12.9'	138°14.7'	B	–	–
84-30-10	30 Aug 1984	12:16	69°13.3'	138°15.7'	A	–	–
84-42-02	2 Sep 1984	14:43	69°22.0'	138°42.0'	A	11.8	4
84-42-13#1	2 Sep 1984	15:22	69°22.3'	138°41.8'	A	11.8	4
84-42-14#2	2 Sep 1984	15:23	69°22.4'	138°43.2'	A	11.6	3
84-42-19#1	2 Sep 1984	15:36	69°22.5'	138°41.8'	B	11.8	5

* "–" indicates no length measurement available.

Herschel Island in a group of eight whales. Measurements were obtained for three of these individuals: a calf (6.6 m) and two sub-adults (9.9 and 10.9 m). A single usable measurement of this whale was obtained in 1982, 12.1 m on 16 August.

In 1984, this individual was photographed about 90 km north of Shingle Point in a group of 25 whales. It measured 12.6 m and the 11 measured whales in the group ranged from 7.5 to 13.0 m (see Figure 21). On 30 August this individual was about 80 km ESE and 120 km SE of its 16 August and 4 September 1982 positions.

The second resighting in Table 14 involved a female that was photographed three times, with a calf, about 25 km due east of Herschel Island on 24 August 1982 (Fig. 26; see Plate 5 in Davis et al. 1983). This whale was re-photographed two years later on 1 September 1984 in Franklin Bay (Fig. 25). The sightings in the two years were about 510 km apart. In 1984, this female was with a loose group of 33 large whales that we photographed for over an hour in Franklin Bay. The smallest of 26 measured whales was 10.2 m and only one other was less than 12 m long. Sixteen whales were larger than 13.0 m with the largest animal being 14.8 m. Thus, although the group contained many reproductively capable animals, no calves or yearlings were present.

The whale referred to above was the smallest female with calf measured to date. The average of her two length measurements in 1982 was 12.2 m. The single measurement in 1984 was 12.5 m. These measurements were all of suboptimal grade (Table 14). It is not possible to determine growth rates with one or only a few measurements, particularly of these grades. Relatively large sample sizes are needed to account for the variability in individual measurements.

The third inter-year resighting involved a subadult individual that was first photographed about 55 km north of Herschel Island on 4 September 1982. The animal was rephotographed on six occasions on two days in 1984 (30 August, 2 September; Fig. 26, Table 14). On 30 August 1984 the whale was about 110 km SSE of its location in 1982. The available length measurements for the two years suggest a low rate of growth for this species (Table 14). The data also demonstrate why relatively large sample sizes will be necessary to overcome the variability associated with individual measurements.

In 1982, the above animal was closely associated with another subadult of 11.6 m length. The four other whales in the immediate vicinity consisted of two cow-calf pairs. The adult females were 13.2 and 13.9 m in length. When the whale was rephotographed on 30 August 1984 it was in a loose group of 10 whales. Measurements of four other whales in this group were 8.2, 8.5, 9.1 and 10.6 m. When the whale was photographed again on 2 September 1984 it was in a group of five whales. The other four whales in the group measured 8.5, 9.4, 9.8 and 11.7 m. The measurement data for the two dates in 1984, in conjunction with the lack of other inter-day re-identifications, suggest that the resighted whale was associated with different subadult animals on 30 August and 2 September.

Expected Number of Resightings

It is possible to calculate the theoretical number of inter-year resightings that should have occurred between the 1982 and 1984 studies, given the following assumptions:

1. the population size is 4000 whales, excluding young of the year,
2. the population size has not changed between 1982 and 1984,
3. all whales have an equal chance of being photographed,
4. whale markings remain identifiable between years and all resightings are recognized.

Based on 204 Grade A photographs in 1982 and 186 Grade A photos in 1984, we expect 9.5 between-year matches to occur. In fact, only three resightings were documented.

The available data suggest that our third assumption was seriously violated. All whales did not have an equal chance of being rephotographed in the two years. Length measurements were available for 81% (167 of 206) of the Grade A photographs from 1982 and 74% (137 of 186) of the Grade A photographs from 1984. The length distributions for the whales represented by Grade A photos are depicted for the two years in Fig. 28. There are substantial differences between the two distributions. Larger numbers of adult whales (over 13 m) were present in the 1982 sample (96 of 167 animals, 57%) than in the 1984 sample (50 of 137 animals, 36%). Higher numbers of small, subadult animals were measured in 1984; these animals were nearly absent in the 1982 sample of Grade A images. It is obvious, therefore, that different segments of the population were sampled in 1982 and 1984. This probably explains, at least partly, the lower than expected number of between-year resightings made in 1984.

Probability of Future Re-identifications

Re-identification of whales in the future depends on the permanency of scar patterns and white pigmentation patterns on the lower jaw and in the fluke/caudal region. If large changes in markings occur, then it is possible that few inter-year re-identifications will be made. However, examination of the three inter-year matches made in 1984 suggests that no changes occurred between 1982 and 1984.

Three images of the first whale shown in Table 14 were available from 1982. This whale was Class C (a small amount of white) on the lower jaw and Class C (no white) in the fluke/caudal region. The whale in the single photograph from 1984 was in turbid water, and the jaw is slightly open. These factors tend to obscure the lower jaw pigmentation, but it does not appear to be different from the 1982 images. No pigmentation is evident in the fluke/caudal region. The scar index (see Appendix 3) from the three 1982 images is at least 22 (1 major, 2 moderate and 2 minor scars) and additional scars may be obscured by wash on the whale's back. Only one moderate and three minor scars are evident on the 1984 image (scar index = 8). The 1984 moderate scar was classed as a major scar in 1982 and one of the 1984 minor scars was classed as moderate in 1982. These discrepancies appear to be related to differing lighting conditions and the attitude of the whale rather than actual changes in the magnitude of the scars; such differences are often apparent even in consecutive photographs of the same whale.

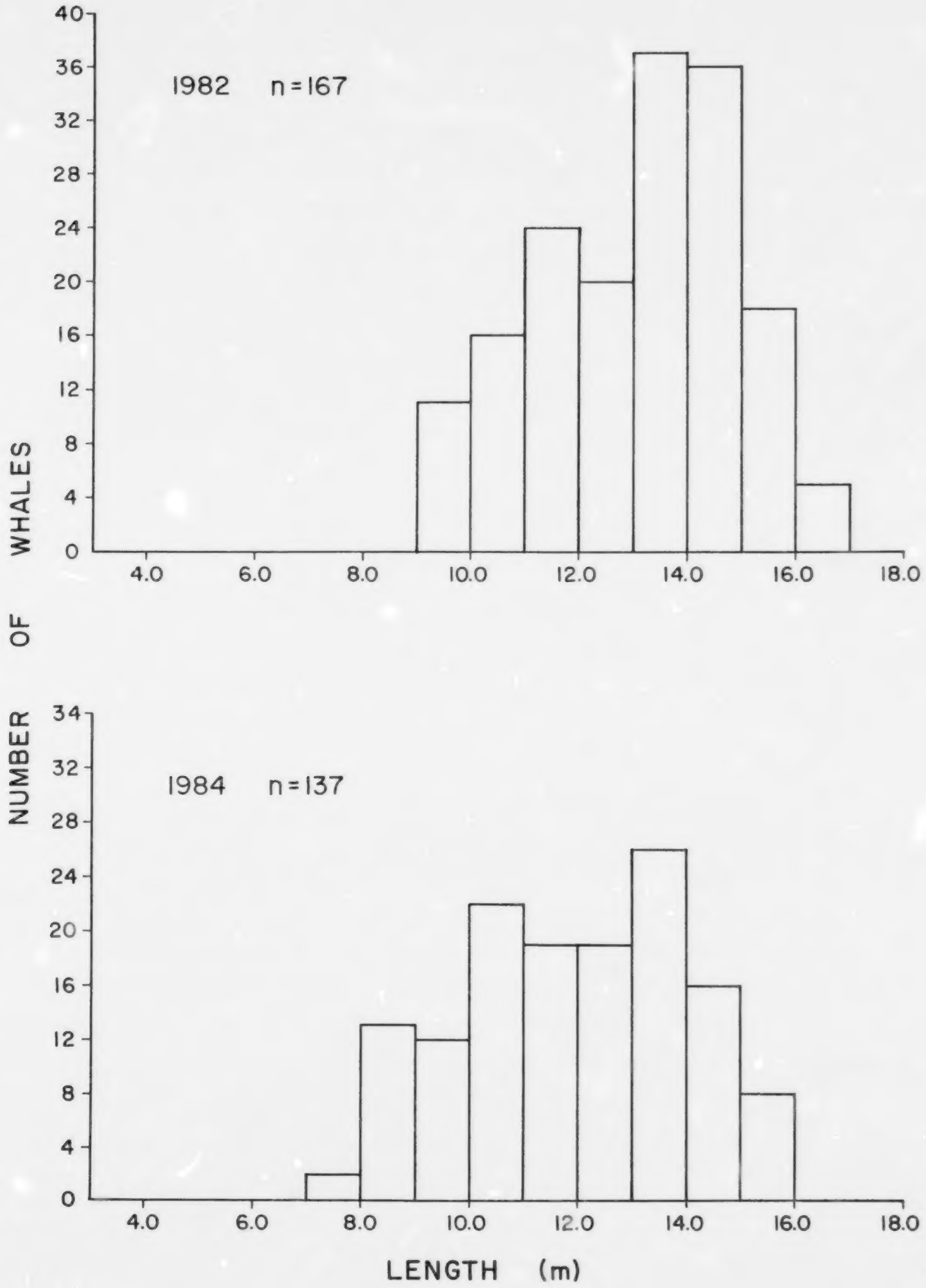

FIG. 28. Length-frequency distributions of re-identifiable (Grade A) whales photographed in 1982 and 1984 (within-year duplicate measurements are excluded).

Three photographs of the female with calf were available from 24 August 1982 (Table 14). This whale was not particularly well-marked with white pigmentation: Class D (little or no white) on the lower jaw and Class B (moderate amount of white) on the fluke/caudal region. It was not possible to grade the jaw and fluke regions of this whale from the single photograph available from 1 September 1984. The scar index of this animal in 1982 was 17--one major and seven minor scars. The major scar and two of the minor scars were present in the 1984 photograph but the locations of the other five minor scars were obscured in 1984.

The third re-identified whale had one moderate and six minor scars in the 1982 photograph (Table 14). All of these scars were present in identical positions in the six photographs of this whale taken in 1984. The patterns of white pigmentation on the lower jaw (Grade D--little or no white) and fluke/caudal region (Grade C--no white) were the same in 1982 and 1984. Thus, the available evidence suggests that the markings used to identify individual whales between years are long-lasting. However, larger sample sizes are needed.

Photographs that are of sufficient quality and that contain well-marked whales that could be re-identified in future years are given Re-identification Grade A status. The number of Grade A photographs available are summarized in Table 15. Overall, 445 Grade A images of

Table 15. Numbers of re-identifiable (Grade A) photographs of different bowheads obtained in various studies in the Canadian Beaufort Sea.

Year	Number	Source
1981	37	Davis et al. (1982)
1982	204	Davis et al. (1983)
1983	12	Cubbage et al. (1984)
1983	1	LGL Ltd., unpubl.
1984	186*	this study
1984	8	U.S. Nat. Mar. Mamm. Lab.
Total	445	

* Three of these whales were also photographed in 1982.

445 different whales are now available for comparisons with photographs from future years.

Life History Parameters

Photogrammetric studies of bowhead whales provide a variety of information about the life history of the species. This is especially important for bowheads, whose life history and reproductive parameters are very poorly understood. Of particular relevance to the present study is information that converts data on whale length to information on whale age. For example, how old were the large numbers of relatively small animals found in the South Industrial Zone and along the Yukon coast in the present study?

Lengths of Calves

In our 1982 study, bowheads ranging in length from 4.1 to 7.6 m were considered to be calves-of-the-year (Davis et al. 1983). To further evaluate this division and to assess the data from 1984, we visually examined the images of all whales that were known to be less than 8.0 m in length. Only measurement grades 1 to 4 were included in this analysis. Each image was visually classified as a calf or yearling without reference to the actual length of the specific whale. Young calves (<6.5 m long) are usually easily distinguished from yearlings based on the following criteria:

1. the mother often accompanies the calf,
2. calves are light colored and often uniformly mottled,
3. the head appears narrow in relation to the width of the body, and
4. calves appear stout or rotund in relation to their length.

As calves grow they become more difficult to distinguish from yearlings. They spend less time in close proximity to their mothers (Davis et al. 1983), their background color darkens, they are usually mottled but mottling becomes more patchy (and similar to mottling in older whales), the head appears to be proportionately wider (as the baleen starts to grow?), and overall the calves become slimmer in appearance.

The sample of small whales (<8 m) included 43 images from 1982 and 18 from 1984 (Table 16). Overall, we judged that we could classify 93.4% (57 of 61) of the whales unambiguously to either the calf or yearling category. Four whales (6.6%) could not be classified to either category. The four whales included individuals of 7.0, 7.3, 7.5 and 7.5 m in length. Thus, the four whales for which some doubt about age existed ranged from 7.0 to 7.5 m in length.

Table 16. Classification of small (<8.0 m) bowhead whales as calves or yearlings based on morphological characteristics or presence of mother without knowledge of length.*

	Identified as Calves	Identified as Yearlings	Unknown	Total	Mother Present in at least one photo
Length 7.50-8.00 m					
1982	0	3	0	3	0
1984	1	9	0	10	0
Length <7.50 m					
1982	35	3	2	40	19
1984	5	1	2	8	2

* Only Measurement Grades 1 to 4 are included.

The largest calves identified in the late summers of 1982 and 1984, based on length, were 7.5 and 7.6 m, respectively. The smallest yearlings identified, based on morphology, were 7.2 m in 1982 and 7.4 m in 1984. Thus, in the two years, there was an apparent zone of overlap between lengths of calves and yearlings that ranged from 7.2 to 7.6 m. Overall, four of 48 (8.3%) whales estimated to be calves because they were smaller than 7.5 m were judged to be yearlings based on morphology and in the absence of information on whale length. An additional four whales could not be classified based on morphology alone. By comparison, only one 7.6 m whale of 14 whales (7%) between 7.5 and 8.0 m was judged to be a calf based on morphology. Larger samples and more analyses are required to determine whether length or morphology is a better predictor of the age of whales that are 7 to 8 m long during late summer.

Lengths of Yearlings

As noted in previous sections, there is some doubt about the size of yearlings. Nerini et al. (1984) concluded that yearlings ranged up to 10.0 m in length in September. The photogrammetric data from the Canadian Beaufort Sea in August and September of 1982 and 1984 are presented in Fig. 29. We interpreted the 1982 data to indicate that calves ranged up to 7.6 m in length, inclusive. The next grouping of lengths evident in the 1982 data included the range from 7.61 m to 8.7 m. We tentatively concluded that this group of animals represented yearlings (Davis et al. 1983).

Interpretation of the measurements from 1984 is somewhat more difficult. A reasonable division between calves and yearlings is 7.5 m (Fig. 29). Examination of the morphological characteristics of the five whale images with lengths between 7.1 and 7.5 m revealed that two of the whales may have been yearlings (7.3 and 7.4 m) and three could not be classified (7.1, 7.3 and 7.5 m). It should be noted that Fig. 29 includes measurement grades 5 and 6, whereas the analysis in Table 16 does not; therefore, the numbers in the two analyses are not directly comparable.

The interpretation from 1982 data that yearlings ranged in length from 7.6 to 8.7 m was apparently also applicable to the 1984 data. In 1984, this group encompassed the range from 7.51 m to about 8.7 m. Clearly, larger sample sizes are required to confirm this interpretation of yearling length. In addition, more work on the morphological characteristics and the zones of overlap between age classes is needed.

If it is assumed that yearlings extend only up to about 8.7 m, then it is tempting to speculate on the significance of the apparent groupings of lengths around 9 m and 9.7-10 m. Similar patterns were vaguely discernible

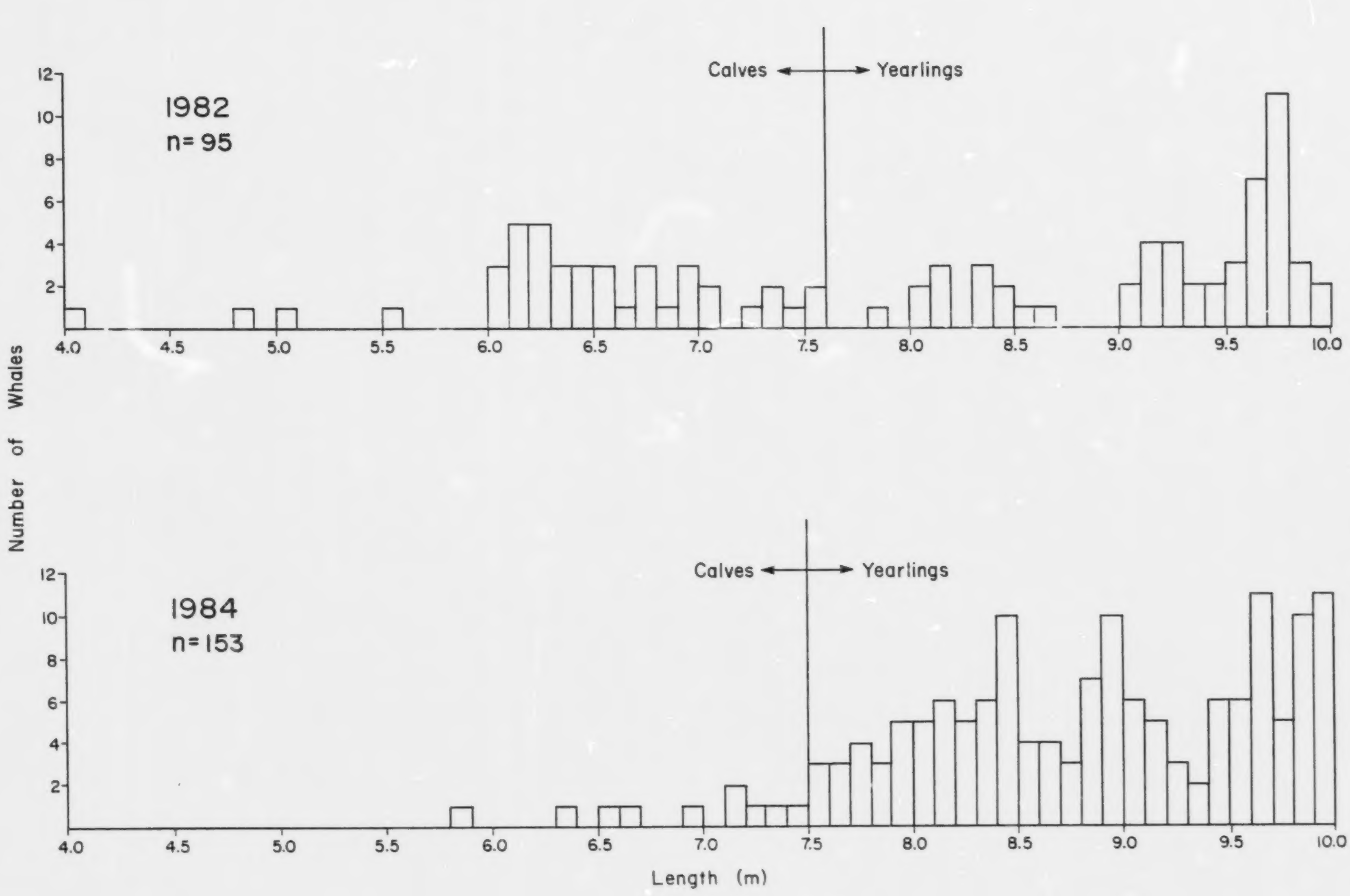

FIG. 29. Length-frequency distributions (repeat measurements excluded) of small (<10 m) bowhead whales photographed in the Canadian Beaufort Sea, 12 August-5 September 1982 and 14 August-14 September 1984. (1982 data from Davis et al. 1983.)

in the 1982 data, although not centred at exactly the same lengths. Further speculation on this question is deferred until the results of our 1985 photogrammetric study can be analyzed.

Length of Calves at Weaning

Davis et al. (1983) demonstrated that, although the behavior of cow-calf pairs did not appear to change during the period of their study, small calves were more likely to be photographed with their mothers than were large calves. The largest calf that they found accompanied by an adult was 7.0 m. The largest calf that was accompanied by an adult in photographs taken in 1984 was 6.6 m. When our two years of data are combined, no calf larger than 7.0 m has been photographed while accompanied by its mother. Cubbage et al. (1984) report that the largest calf accompanied by an adult in their photographs was also 7.0 m.

In 1982, eight animals were between 7.01 and 7.6 m in length--i.e. calves based on the length criterion. Three of these eight whales would have been classed as yearlings based on morphology alone. In 1983, Cubbage et al. (1984) thought that their largest calf was 7.8 m long; they recorded eight whales between 7.0 and 7.8 m. These workers did not examine the morphology of these animals. In 1984, the largest calf was estimated to be 7.5 m. Five animals between 7.01 and 7.5 m were measured; two of these were thought to be yearlings based on morphology. Over the three years, 21 whales over 7.0 m have been classed as calves based on lengths. Only two of these whales (both 7.0 m) were photographed with their mothers. Not all of the remaining 19 whales were actually calves. Based on combined 1982 and 1984 data, 38% (5 of 13) of them would have been classified as yearlings based on morphology alone and 38% could not be classified to either category.

Once again, larger sample sizes of whales in the 7 to 7.5 m range are needed to determine whether weaning occurs at about 7.0 m in length or whether lactation continues for nearly one year as suggested by Nerini et al. (1984). During late summer, bowhead calves have been observed to remain separated from their mothers for as much as 1.2 h, but then to rejoin the mother and nurse (Würsig et al. 1985a). Thus, calves photographed away from their mothers may not yet be weaned. It is also noteworthy that mother-calf pairs are often seen during the autumn migration through Alaskan waters in September and October (e.g., Ljungblad et al. 1985a).

Lengths of Females with Calves

During the present study, four different adult whales were photographed in close association with a calf. Direct length estimates were obtained for two pairs--a 13.8 m female with a 5.8 m calf, and a 14.2 m female with a 6.6 m calf. A minimum length of 14.6 m was projected for a third mother based on an oblique photograph of her fluke. No measurement could be obtained for the fourth mother. These data are similar to the larger samples from 1982 (Davis et al. 1983).

Gross Annual Reproductive Rate

There is great interest among hunters, managers and regulators regarding the reproductive rate of the bowhead whale. Of particular interest has been the Gross Annual Reproductive Rate (GARR) which is the number of calves as a percentage of the number of non-calves in the population. It is always tempting to add the data from each study to the accumulating data base on reproductive rates. We do not believe that it is a useful exercise to calculate a value for GARR based on the present study. Such a value would be misleading for a variety of reasons. The study was not designed to take an unbiased sample of the entire population since our work was focused in only part of the summer range. Furthermore, the study was not designed to take an unbiased sample of even the areas studied. Repeated samples were attempted in areas in and adjacent to the industrial zones, whereas less intensive sampling occurred in some of the control areas. Thus, our study design was not appropriate for an evaluation of GARR.

In addition to the design considerations mentioned above, calculation of GARR in 1984 was greatly complicated by the obvious age segregation of the population. Inspection of the length distributions in each of the study zones clearly demonstrates this age segregation. Also, inspection of the overall length frequency data (Fig. 10) indicates that a large proportion of the adult component of the population was not sampled at all. Therefore, we have not calculated GARR from the data acquired during the present study.

DISCUSSION

Distribution Patterns

The distribution of bowheads in the Canadian Beaufort Sea was clearly not uniform in 1984. Whales were concentrated in some areas but uncommon or absent from other areas. Richardson et al. (1985d) have summarized the distributional data from all 1984 studies (including the present study) of bowheads in the Canadian Beaufort. They have related distribution patterns observed in 1984 to those in the previous years and to the presence and distribution of industrial activities in the area. The details of these comparisons will not be repeated here. The important point is that all studies confirmed that few bowheads used the zone of offshore industrial activity in 1984. Most of the whales that were in the industrial area in 1984 were near its eastern, western or northern edges. The scarcity of whales in the industrial zone made it difficult to address some of the objectives of our study because available sample sizes were, of necessity, small.

Large numbers of bowheads were present in the Interface and King Point zones throughout the study period. This pattern was similar to 1983 but quite different than 1980-82 when concentrations did not occur along the Yukon coast. In 1984, substantial numbers of whales were recorded in the Herschel Island and Komakuk zones on some occasions. At other times, very few whales could be found in these two zones. It was our impression that whales in the Herschel Island Zone tended to be moving through the area.

Bowheads were consistently present in Franklin Bay, including the Cape Bathurst area, in 1984. Bowheads have been found in Franklin Bay in each of the years (1981, 1982, 1983) that the area has been searched.

Industrial Activity

The amounts and locations of offshore industrial activities are summarized earlier in the report. On a ranking scale from most to least industry activity, our seven study zones ranged from South Industrial, North Industrial, Interface, Herschel Island, Komakuk, King Point, and Franklin

Bay. Franklin Bay was essentially undisturbed and served as the main control area. The King Point Zone was adjacent to industrial activity and some underwater noise reached parts of the zone on occasion. Komakuk was exposed to seismic activity in early August and early September but was basically undisturbed at other times.

Age Composition in 1984

One of the principal objectives of this study was to determine which age classes of whales use the southeastern Beaufort Sea in summer and to assess whether certain age classes tend to avoid the industrial zones or adjacent areas. The results clearly demonstrate that age segregation occurred in 1984.

Substantial numbers of adult (>13 m) and large subadult whales occurred in only two of our seven study zones--Franklin Bay and North Industrial Zone (Fig. 10). Based on resightings of individuals, constancy of numbers between days, and similarity of length distributions on different days, it is apparent that the large whales tended to remain in the Franklin Bay control area. On the other hand, evidence from the North Industrial Zone suggests that the large whales were generally at least 10 km north of the drillships and that they apparently did not linger in this zone.

The whales in the other five zones were significantly smaller than in the North Industrial and Franklin Bay zones. Very few adults (less than 5%) were present in any of the five zones. In most zones, the majority of the animals were less than 11 m in length. A striking feature of all four zones along the Yukon coast (including the Interface Zone but excluding the South Industrial Zone because of its small sample sizes) was the high proportion of yearlings in the samples. Fully 20% of the measured animals along the Yukon coast were yearlings according to the length criterion of 7.6 to 8.7 m. If the yearling criterion of Nerini et al. (1984) is used, then 51% of the measured whales would have been yearlings. In any event, it is clear that most of the whales along the Yukon coast were young, immature animals. It is also clear that very few calves of the year were present in any of our seven study zones.

Age Distribution in Previous Years

Length measurements from aerial photographs of bowheads have been obtained in 1981 (65 measurements--Davis et al. 1982), 1982 (361--Davis et al. 1983), and 1983 (197--Cubbage et al. 1984). The objectives and designs of these three studies and of the present study were all different; thus, the results are not directly comparable. However, some patterns can be discerned.

Whales in Amundsen Gulf (including Franklin Bay) tend to be large adult and near adult animals. Very few, if any, calves, yearlings or other small immatures are present. This pattern was indicated in 1981 when 27 animals in a group of 32 in deSalis Bay, Banks Island, ranged from 12 to 17 m; 96% of these were adults over 13 m (Davis et al. 1982). No photographs were taken in Amundsen Gulf in 1983 but Cubbage et al. (1984) obtained 43 measurements in Franklin Bay in 1983. These animals ranged from 11.5 to 18 m with no calves or yearlings present. Overall, 91% of these animals were adults over 13 m. We obtained measurements of 85 different animals on three days in Franklin Bay in 1984 (Fig. 17). Again, the majority (74%) of the animals were over 12 m, although only 48% were over 13 m. Two calves and three yearlings were found in early September and some other immature whales were also noted. Overall, however, the evidence suggests that Franklin Bay, and perhaps other parts of Amundsen Gulf, are not used as calf-rearing areas nor are they important areas for immature whales.

Preliminary results from northeast Baffin Island suggest that similar areas may occur for the eastern arctic bowhead population. Large numbers of bowheads (65+) were present in the Isabella Bay area in late August and September 1984. No calves or immature animals were present (K.J. Finley, LGL Ltd., pers. comm.).

No measurements are available from the industrial zone except for those that we obtained in 1984. Thus, no comparisons with previous years are possible.

The concentration of large numbers of whales in the King Point Zone from Shingle Point to Kay Point along the Yukon coast also occurred in 1983 but did not occur in 1981 or 1982. Cubbage et al. (1984) did not photograph these animals but a small sample of 14 Grade 1-4 measurements was obtained in the King Point and Interface zones by W.R. Koski, LGL Ltd. These animals were photographed and measured using the same techniques as those in the present study. The average length of the 14 measured whales was 9.8 m with a range of 7.3 to 12.1 m. [The 14 measurements used here are a subset of the 22 presented by Würsig et al. 1985b, which included lower quality measurement grades.] Thus, in the two (of four) years when concentrations occurred in the King Point and Interface zones, similar age distributions occurred--i.e. subadult animals with high numbers of yearlings.

In 1982, large numbers of bowheads, including adults with calves, occurred north of Herschel Island over the deep waters of Herschel canyon. These animals also ranged northeast along the shelf-break. In 1984, virtually no whales were present in these areas, which were covered by heavy ice (8/10+) much of the time. Similarly, offshore areas where adults and calves were found by Cubbage et al. (1984) in 1983 did not contain animals in 1984 or were not photographed. Thus, comparative measurements are not available for these areas in 1984.

Cubbage et al. (1984) found a significant inverse correlation between longitude and whale length--i.e. larger whales tended to occur farther east in the summer range. A similar trend undoubtedly occurred in 1984. However, we have not calculated a correlation coefficient for 1984 because the situation appears to be more complex. The length distribution from 1982 seems to counter the trend from 1983 and 1984. We believe that the relationship proposed by Cubbage et al. deserves further investigation using all available data, including the large samples obtained in 1985. The analysis should also include factors such as water depth and distance from the coast. The general pattern from 1984, and 1982 to some extent, suggests that small, subadult classes tend to occur in shallow water that is often near shore and turbid. The larger animals, including adults with calves, tend to occur in deep (>200 m) waters. A multivariate analysis of this question is desirable. The analysis should include year and date terms to account for inter-year and seasonal differences (see Thomson et al. 1985).

Habituation

North and South Industrial Zones

One of the objectives of this study was to determine whether individual bowheads remain near industrial sites for prolonged periods. In other words, do bowheads habituate to nearby industrial activity. This objective turned out to be difficult to address directly because so few whales occurred in the North and South Industrial zones. The fact that few animals used the areas is an interesting finding on its own. However, the lack of animals does not necessarily indicate an industrial effect; it may have been due to some unmeasured natural factor such as lack of concentrated food sources in the industrial zones. The point of interest to the present discussion is how the animals that did occur near industrial activities behaved.

In spite of fairly intensive survey coverage (Table 6), our maximum corrected population estimate for the North and South Industrial zones was 138 animals on 22 August. The variable numbers seen from day-to-day during the surveys, during the aerial searches (Figs. 11-13), and by other workers (Figs. 7-9) suggest that turnover rate was very high in these areas. The unsuccessful efforts to track the three groups of whales (22-5, 2-6, 5-1) that were found in the North and South Industrial zones indicate that the groups were probably passing through the areas. Similarly, no individual whales were resighted in the two zones. Thus, there was no evidence that whales remained in the two zones for extended periods.

An interesting fact was that the group (22-5) in the South Industrial Zone consisted of small, subadult animals in shallow, turbid waters. These animals were clearly within the general zone of industrial activity, although not near any active offshore site. The two groups in the North Industrial Zone in early September consisted of large, mostly adult animals; they were in clear waters (30-100 m deep) about 10-22 km north of the northernmost drillship.

The rapid turnover rates and short residence times in the industrial zones need to be assessed relative to residence times in adjacent control zones.

Franklin Bay

The behavior of the whales in Franklin Bay was quite different than that found in the industrial zones or along the Yukon coast. Concentrations of whales tended to occur in the same part of Franklin Bay from day to day, the length distributions were basically similar on different days, and most importantly, four individuals were resighted on more than one day. The resighting rate was significantly higher in Franklin Bay (7.8%) than along the Yukon coast (0.9%). There were no resightings at all in the industrial zones or in the Interface Zone. In addition, the time between resightings was much longer in Franklin Bay (mean = 10.2 days) than along the Yukon coast (mean = 2.0 days). The imputed net rate of movement was much slower for the resightings in Franklin Bay (0.1 km/h) than for those along the Yukon coast (1.4 km/h).

The four resighted animals in Franklin Bay were larger (mean = 14.1 m) than the three resighted whales along the Yukon coast (mean = 9.7 m). It is possible that larger, adult whales tend to be more sedentary than smaller subadults. Re-examination of the resighting data (n = 14) from 1982 showed no relationship between whale length and rate of movement or time between resightings. However, none of the 1982 resightings came from the Franklin Bay area. Whatever the reasons, the stability of the distribution patterns in Franklin Bay was very different from the situation along the Yukon coast in 1984.

Yukon Coast

In the present discussion of the Yukon coast we include the Interface, King Point, Herschel Island, and Komakuk zones. Overall, the four zones had substantially more industrial activities than Franklin Bay but less than the North and South Industrial zones. The available data from the Yukon coast suggest very rapid day-to-day turnover of animals in any particular area.

There are three possible explanations for this behavior. The explanations may be interrelated. The turnover and rapid movements over considerable distances may be an intrinsic component of the behavior of the small, subadult bowheads that formed the majority of animals in these areas; however, the same rapid turnover rate was not recorded among similar sized whales during 1985 studies conducted along the Yukon coast. In addition, this would not explain why the larger subadults and the few adults that occurred along the Yukon coast also seemed to exhibit the rapid turnover rates. In addition, studies conducted in the same area in 1985 found very low rates of movement for small whales indicating that small whales do not intrinsically move more rapidly than larger whales.

The second possible explanation is that the whales are responding to the generally higher levels of industrial activities and potential disturbance along the Yukon coast than in Franklin Bay. The evidence from the few animals actually present in the North and South Industrial zones indicates that high turnover rates also occurred there. If industrial disturbance was an important factor, it would be reasonable to assume that patterns might be different in the Komakuk and King Point zones, which had little activity, compared with the Interface and Herschel Island zones. No such differences could be discerned but sample sizes may not be large enough to document these smaller-scale differences.

The third possible explanation for the high turnover rates is that the local oceanographic conditions are highly variable, on almost a daily basis. These variations could cause major changes in the locations and concentrations of zooplankton available to the whales. This is an attractive explanation because there is already some evidence that physical oceanographic conditions do change rapidly along the Yukon coast (Borstad 1985; Harwood and Borstad 1985; Thomson et al. 1985). It is not known how these remotely sensed changes in physical oceanographic conditions affect the quantity and availability of food for bowheads. If food availability was changeable from area to area, then we would expect local whale distribution patterns to change in response to the food. Thus, all whales might leave an area where concentrated food was no longer available and travel to areas where food was more plentiful. This did not appear to occur. When some individual whales left an area, they were often replaced by different individuals. Movements in response to changes in food availability may have occurred, but the situation was not simply a uniform response by all individual whales to major shifts in food availability. Studies of the actual food organisms present in the Yukon coast zones in 1985 may shed some light on this question.

Long-term Habituation

Another of the objectives of this study was to determine whether bowheads return to areas where they encountered industrial activity in a previous year. The question is at the heart of the hypothesis that bowheads learn to avoid the industrial zone in the Canadian Beaufort Sea (ESL Ltd. et al. 1985). This objective could not be addressed directly because no photographs from the industrial zone were available from previous years. Our plan was to obtain photographs from the industrial area in 1984 for comparison with future years and to begin to address the question by determining whether bowheads returned to the same non-industrial areas where they had been photographed previously.

This indirect objective was hindered by the lack of inter-year re-identifications. Only three were made rather than the nine that were expected. This lower number was related to the different segments of the population photographed in the two years (1982 and 1984). For example, the concentration of immature animals along the Yukon coast in 1984 was not present in 1982, and no photographs were taken in Franklin Bay in 1982. In contrast, the large groups of adults, many with calves, that were present north of Herschel Island and along the shelf break were not present in 1984. Thus, it is not surprising that few inter-year re-identifications were made.

The three resightings that were made suggest that bowheads may not show much site-fidelity between years. Resightings in 1984 ranged from 80 to 510 km from where the whales were photographed in 1982.

Two of the whales were originally photographed near Herschel Island in 1982. In one case, a 12.1 m whale was photographed north of Herschel Island on 16 August and 4 September. It was re-photographed on 30 August 1984 about 80 and 120 km from its 1982 locations. This whale was photographed in groups of whales ranging from eight to more than 250 individuals and consisting of calves, sub-adults and adults. A second inter-year resighting involved an immature animal (11.8 m) that was north of Herschel Island on 4 September 1984 and near King Point on 30 August 1984. In 1982, the animal was with another immature plus two cow-calf pairs. In 1984, it was seen on two different days (30 August, 2 September) associated with different immature animals on the two days. The third case involved a female that was photographed with a calf about 40 km north of King Point on 24 August 1982 and without a calf in central Franklin Bay on 1 September 1984. On the latter date, she was present in a group of mostly large, potentially breeding animals; no calves or yearlings were present. The data are sparse but it can be hypothesized that factors that determine whether animals return to a particular area in future years include the age of the animal and stage of breeding cycle.

Many of the data collected in this study cannot be fully interpreted at present. As more photographs are collected in future years and the 1984 data are compared with them, an understanding of the distribution and movement patterns, turnover rates, age segregation, and basic reproductive biology of the bowhead will unfold. The importance of length data and individually identifiable animals for proper interpretation of distribution patterns is clearly demonstrated by this study.

LITERATURE CITED

Acoustical Society of America. 1981. San Diego workshop on the interaction between man-made noise and vibration and arctic marine wildlife. Rep. by Acoustical Soc. Am., Washington, for Alaska Eskimo Whaling Comm., Barrow, AK. 84 p.

Borstad, G.A. 1985. Water colour and temperature in the southern Beaufort Sea: remote sensing in support of ecological studies of the bowhead whale. Can. Tech. Rep. Fish. Aquat. Sci. 1350, 69 p. + plates.

Braham, H.W. and D.J. Rugh. 1983. Report of the first of two workshops on the development and evaluation of a photo identification system for bowhead whales held 6-7 January 1983. Rep. by Nat. Mar. Mamm. Lab., Seattle, WA. 26 p.

Breiwick, J.M., L.L. Eberhardt and H.W. Braham. 1984. Population dynamics of western arctic bowhead whales (*Balaena mysticetus*). Can. J. Fish. Aquat. Sci. 41:484-496.

Clark, C.W. and J.H. Johnson. 1984. The sounds of the bowhead whale, *Balaena mysticetus*, during the spring migrations of 1979 and 1980. Can. J. Zool. 62(7):1436-1441.

Cubbage, J.C., J. Calambokidis and D.J. Rugh. 1984. Bowhead whale length measured through stereophotogrammetry. Rep. by Cascadia Res. Collective, Olympia, WA, for Nat. Mar. Mamm. Lab., Seattle, WA. 71 p.

ESL Ltd. et al. 1985. Beaufort Environmental Monitoring Project 1984-85 Final Report. Rep. by ESL Environmental Sciences Ltd., LGL Ltd., ESSA Ltd., Arctic Laboratories Ltd. and Arctic Sciences Ltd., for Dept. Indian and Northern Affairs Canada and Environment Canada.

Davis, R.A., W.R. Koski and G.W. Miller. 1983. Preliminary assessment of the length-frequency distribution and gross annual reproductive rate of the western arctic bowhead whale as determined with low-level aerial photography, with comments on life history. Rep. by LGL Ltd., Toronto, for U.S. Nat. Mar. Mamm. Lab., Seattle, WA. 91 p.

Davis, R.A., W.R. Koski, G.W. Miller, P.L. McLaren and C.R. Evans. 1986a. Reproduction in the bowhead whale, Summer 1985. Rep. by LGL Ltd., King City, for Standard Alaska Production Company et. al. Draft final. 157 p.

Davis, R.A., W.R. Koski, G.W. Miller, P.L. McLaren and C.R. Evans. 1986b. Reproduction in the bowhead whale, summer 1985. Rep. from LGL Ltd., King City, Ont., for Standard Alaska Prod. Co. et al., Anchorage, AK. Int. Whal. Comm. Doc. SC/38/PS2. 123 p.

Davis, R.A., W.R. Koski, W.J. Richardson, C.R. Evans and W.G. Alliston. 1982. Distribution, numbers and productivity of the Western Arctic stock of bowhead whales in the eastern Beaufort Sea and Amundsen Gulf, summer 1981. Rep. by LGL Ltd., Toronto, for Sohio Alaska Petrol. Co. and Dome Petrol. Ltd. (co-managers). 134 p. Summarized as Int. Whal. Comm. document SC/34/PS20.

Fraker, M.A., W.J. Richardson and B. Würsig. 1982. Disturbance responses of bowheads. p. 145-248. *In*: W.J. Richardson (ed.), Behavior, disturbance responses and feeding of bowhead whales *Balaena mysticetus* in the Beaufort Sea, 1980-81. Rep. by LGL Ecol. Res. Assoc., Inc., Bryan, TX, for U.S. Bureau of Land Management, Washington. 456 p.

Geraci, J.R. and D.J. St. Aubin. 1980. Offshore petroleum resource development and marine mammals: a review and research recommendations. Mar. Fish. Rev. 42(11):1-12.

Greene, C.R. 1985. Characteristics of waterborne industrial noise, 1980-84. p. 197-253. *In*: W.J. Richardson (ed.), Behavior, disturbance responses and distribution of bowhead whales *Balaena mysticetus* in the eastern Beaufort Sea, 1980-84. Chapter by Greeneridge Sciences, Inc., in Unpubl. Rep. from LGL Ecol. Res. Assoc., Inc., Bryan, TX, for U.S. Minerals Management Service, Reston, VA. 306 p.

Harwood, L.A. and G.A. Borstad. 1985. Bowhead whale monitoring study in the southeastern Beaufort Sea, July-September 1984. Rep. by ESL Environmental Sciences Ltd., Sidney, B.C., for Envir. Stud. Revolv. Fund, Dept. Indian Affairs and Northern Development, Ottawa.

Harwood, L.A. and J.K.B. Ford. 1983. Systematic aerial surveys of bowhead whales and other marine mammals in the southeastern Beaufort Sea, August-September 1982. Rep. by ESL Environmental Sciences Limited, Sidney, B.C., for Dome Petroleum Ltd. and Gulf Canada Resources Inc., Calgary. 76 p.

Hazard, K.W. and L.F. Lowry. 1984. Benthic prey in a bowhead whale from the northern Bering Sea. Arctic 37(2):166-168.

International Whaling Commission. 1984. Report of the scientific committee: Annex G (protected species). Rep. Int. Whal. Comm. 34:130-144.

Jacobson, R.E. 1978. The manual of photography. Focal Press Ltd., London. 628 p.

Ljungblad, D.K., S.E. Moore, J.T. Clarke, D.R. Van Schoik and J.C. Bennett. 1985a. Aerial surveys of endangered whales in the northern Bering, eastern Chukchi and Alaskan Beaufort Seas, 1983: with a six year review, 1979-1984. NOSC Tech. Rep. 1046, Naval Ocean Systems Center, San Diego, CA. 301 p.

Ljungblad, D.K., B. Würsig, S.L. Swartz and J.M. Keene. 1985b. Observations on the behavior of bowhead whales (*Balaena mysticetus*) in the presence of operating seismic exploration vessels in the Alaskan Beaufort Sea. OCS Study, MMS 85-0076. Unpubl. Rep. from SEACO, Inc., San Diego, CA, for U.S. Minerals Management Service, Anchorage, AK. 88 p.

Ljungblad, D.K., P.O. Thompson and S.E. Moore. 1982. Underwater sounds recorded from migrating bowhead whales, *Balaena mysticetus*, in 1979. J. Acoust. Soc. Am. 71(2):477-482.

Lowry, L.F. and J.J. Burns. 1980. Foods utilized by bowhead whales near Barter Island, Alaska, autumn 1979. Mar. Fish. Rev. 42(9-10):88-91.

Lowry, L.F., K.J. Frost and J.J. Burns. 1978. Food of ringed seals and bowhead whales near Point Barrow, Alaska. Can. Field-Nat. 92:67-70.

Marine Mammal Commission. 1979/80. Humpback whales in Glacier Bay National Monument, Alaska. Rep., MMC-79/01. U.S. Marine Mammal Comm., Washington, NTIS PB80-141559. 44 p.

McLaren, P.L. and R.A. Davis. 1985. Distribution of bowhead whales and other marine mammals in the southeast Beaufort Sea, August-September 1983. Rep. by LGL Ltd., Toronto, for the Envir. Studies Revolving Fund, DIAND, Ottawa, and for Dome Petrol. Ltd. and Gulf Canada Resources Inc., Calgary. ESRF Rep. No. 001. 62 p.

Nerini, M.K., H.W. Braham, W.M. Marquette and D.J. Rugh. 1984. Life history of bowhead whales, *Balaena mysticetus* (Mammalia: Cetacea). J. Zool., London 204:443-468.

Nishiwaki, M. and A. Sasao. 1977. Human activities disturbing natural migration routes of whales. Sci. Rep. Whales Res. Inst. 19:113-120.

Norris, K.S. and R.R. Reeves (eds.). 1978. Report on a workshop on problems related to humpback whales (*Megaptera novaeangliae*) in Hawaii. Unpubl. Rep. from Sea Life, Inc., Makapuu Pt., HI, for U.S. Marine Mammal Comm., Washington. 90 p.

Reeves, R.R. 1977. The problem of gray whale (*Eschrichtius robustus*) harassment: at the breeding lagoons and during migration. U.S. Marine Mammal Comm. Rep. MMC-76/06. Nat. Tech. Inform. Serv. PB-272506. 60 p.

Renaud, W.E. and R.A. Davis. 1981. Aerial surveys of bowhead whales and other marine mammals off the Tuktoyaktuk Peninsula, N.W.T., August-September 1980. Rep. by LGL Ltd., Toronto, for Dome Petroleum Ltd., Calgary. 55 p.

Richardson, W.J., R.A. Davis, C.R. Evans and P. Norton. 1983a. Distribution of bowheads and industrial activity, 1980-82. p. 269-357. *In*: W.J. Richardson (ed.), Behavior, disturbance responses and distribution of bowhead whales *Balaena mysticetus* in the eastern Beaufort Sea, 1982. Rep. from LGL Ecol. Res. Assoc., Inc., Bryan, TX, for U.S. Minerals Management Service, Reston, VA. 357 p.

Richardson, W.J., C.R. Greene, J.P. Hickie and R.A. Davis. 1983b. Effects of offshore petroleum operations on cold water marine mammals. A literature review. API Rep. No. 4370. Am. Petrol. Inst., Washington, DC. 248 p.

Richardson, W.J., R.S. Wells and B. Würsig. 1983c. Disturbance responses of bowheads, 1982. p. 117-215. *In*: W.J. Richardson (ed.), Behavior, disturbance responses and distribution of bowhead whales *Balaena mysticetus* in the eastern Beaufort Sea, 1982. Rep. from LGL Ecol. Res. Assoc., Inc., Bryan, TX, for U.S. Minerals Management Service, Reston, VA. 357 p.

Richardson, W.J., P. Norton and C.R. Evans. 1984a. Distribution of bowheads and industrial activity, 1983. p. 309-361. In: W.J. Richardson (ed.). Behavior, disturbance responses and distribution of bowhead whales Balaena mysticetus in the eastern Beaufort Sea, 1983. Rep. from LGL Ecol. Res. Assoc., Inc., Bryan, TX, for U.S. Minerals Management Service, Reston, VA. 361 p.

Richardson, W.J., R.S. Wells and B. Würsig. 1984b. Disturbance responses of bowheads, 1983. p. 101-215. In: W.J. Richardson (ed.), Behavior, disturbance responses and distribution of bowhead whales Balaena mysticetus in the eastern Beaufort Sea, 1983. Unpubl. Rep. from LGL Ecol. Res. Assoc., Inc., Bryan, TX, for U.S. Minerals Management Service, Reston, VA. 361 p.

Richardson, W.J., R.A. Davis, C.R. Evans and P. Norton. 1985a. Distribution of bowheads and industrial activity, 1980-84. p. 255-306. In: W.J. Richardson (ed.), Behavior, disturbance responses and distribution of bowhead whales Balaena mysticetus in the eastern Beaufort Sea, 1980-84. Unpubl. Rep. from LGL Ecol. Res. Assoc., Inc., Bryan, TX, for U.S. Minerals Management Service, Reston, VA. 306 p.

Richardson, W.J., R.S. Wells and B. Würsig. 1985b. Disturbance responses of bowheads, 1980-84. p. 89-196. In: W.J. Richardson (ed.), Behavior, disturbance responses and distribution of bowhead whales Balaena mysticetus in the eastern Beaufort Sea, 1980-84. Unpubl. Rep. from LGL Ecol. Res. Assoc., Inc., Bryan, TX, for U.S. Minerals Management Service, Reston, VA. 306 p.

Richardson, W.J., M.A. Fraker, B. Würsig and R.S. Wells. 1985c. Behaviour of bowhead whales Balaena mysticetus summering in the Beaufort Sea: reactions to industrial activities. Biol. Conserv. 32:195-230.

Richardson, W.J., C.R. Greene and B. Würsig. 1985d. Project rationale and design. p. 1-11. In: W.J. Richardson (ed.), Behavior, disturbance responses and distribution of bowhead whales Balaena mysticetus in the eastern Beaufort Sea, 1980-84. Unpubl. Rep. from LGL Ecol. Res. Assoc., Inc., Bryan, TX, for U.S. Minerals Management Service, Reston, VA. 306 p.

Richardson, W.J., B. Würsig, G.W. Miller and G. Silber. 1986. Bowhead distribution, numbers and activities. p. 146-219. In: W.J. Richardson (ed.), Importance of the eastern Alaskan Beaufort Sea to feeding bowhead whales, 1985. Rep. MMS 86-0026 for U.S. Minerals Manage. Serv., Reston, VA. 315 p.

Schwidefsky, K. 1959. An outline of photogrammetry. Pitman Publ. Corp., N.Y. 326 p.

Sokal, R.R. and E.J. Rohlf. 1969. Biometry. W.H. Freeman, San Francisco. 776 p.

Thomson, D.H., D.B. Fissel, J.R. Marko, R.A. Davis and G.A. Borstad. 1985. Distribution of bowhead whales (Balaena mysticetus) in relation to hydrometeorological events in the southeastern Beaufort Sea, 1980-1983. Report by LGL Limited, King City, Ont.; Arctic Sciences Ltd., Sidney, B.C.; and G.A. Borstad Ltd., Sidney, B.C., to the Environmental Studies Revolving Funds. Dept. of Indian and Northern Affairs, Ottawa. 119 p.

Whitehead, H. and R. Payne. 1981. New techniques for measuring whales from the air. Final Rep. to U.S. Mar. Mamm. Comm. NTIS PB81-161143. 36 p.

Wolfson, F.H. 1977. Gray whale behavior [letter to editor]. Science 195:534-535.

Würsig, B., C.W. Clark, E.M. Dorsey, M.A. Fraker and R.S. Payne. 1982. Normal behavior of bowheads. p. 33-143. In: W.J. Richardson (ed.), Behavior, disturbance responses and feeding of bowhead whales Balaena mysticetus in the Beaufort Sea, 1980-81. Chapter by New York Zool. Soc. in Rep. from LGL Ecol. Res. Assoc., Inc., Bryan, TX, for U.S. Bureau of Land Management, Washington. 456 p.

Würsig, B., C.W. Clark, E.M. Dorsey, W.J. Richardson and R.S. Wells. 1983. Normal behavior of bowheads, 1980-84. p. 13-88. In: W.J. Richardson (ed.), Behavior, disturbance responses and distribution of bowhead whales Balaena mysticetus in the eastern Beaufort Sea, 1982. Rep. from LGL Ecol. Res. Assoc., Inc., Bryan, TX, for U.S. Minerals Management Service, Reston, VA. 357 p.

Würsig, B., E.M. Dorsey, M.A. Fraker, R.S. Payne and W.J. Richardson. 1985a. Behavior of bowhead whales, Balaena mysticetus, summering in the Beaufort Sea: a description. Fish. Bull. U.S. 83(3):357-377.

Würsig, B., E.M. Dorsey, W.J. Richardson, C.W. Clark and R. Payne. 1985b. Normal behavior of bowheads, 1980-84. p. 13-88. In: W.J. Richardson (ed.), Behavior, disturbance responses and distribution of bowhead whales Balaena mysticetus in the eastern Beaufort Sea, 1980-84. Rep. from LGL Ecol. Res. Assoc., Inc., Bryan, TX, for U.S. Minerals Management Service, Reston, VA. 306 p.

APPENDIX 1

DERIVATION OF MEASUREMENTS OF BOWHEAD WHALES

During the period from 14 August to 14 September 1984, we took 972 photographs of bowhead whales. Only 960 of the photographs actually contained images of whales and these contained a total of 1,114 whale images. In addition, 80 photographs of the calibration target were obtained. Before determining the best estimates of whale lengths, it is necessary to calibrate the photographic system and to evaluate potential sources of error.

Calibration of Photography

There are several potential sources of error that could lead to inaccurate calculations of the length of an object from a photograph. Some of these errors can be quantified by photographing objects of known length and comparing the calculated lengths with the known lengths. Some error is caused by image distortion due to vibration and movement of the aircraft. Other sources of error include inaccurate calibration of the altimeter, errors in reading the altitude from the altimeter, the camera not being perpendicular to the water when the photograph was taken, inaccurate nominal focal length of the lens, and errors in measuring the size of the object from the film. The combined effects of these potential errors on our whale measurements are examined here. Other errors that relate primarily to the posture of the whale are discussed in a later section - 'Measurements of re-identified whales'.

Distortion Caused by Aircraft Movement

Aircraft movement causes image distortion that tends to overestimate or underestimate the size of the object on the film. This distortion results from three different potential sources of error. The first source is image elongation due to the forward motion of the aircraft. Assuming a true ground speed of 185 km/h and a shutter speed of 1/500 s, there is a theoretical forward elongation (i.e. image smear) of 0.103 m (Schwidefsky 1959). The other sources of image distortion are vibration and movement of the focal plane shutter across the film. These distortions cannot be quantified easily, but by examining photographs taken at 1/250 s, where forward motion is readily detectable on the film, it is evident that forward motion causes much greater distortion than does vibration. In determining the lengths of the calibration target measurements and the length of whales, we have corrected the calculated lengths for the theoretical elongation due to forward motion assuming a true ground speed of 185 km/h. We have not attempted to correct the lengths for other errors caused by distortion or movement of the focal plane shutters. Cubbage et al. (1984) found an apparent average decrease of 0.77% in length along the direction of flight (11.6 cm for a 15 m whale) because their shutters were oriented to move from the front of the airplane to the back. Thus image elongation due to forward motion of the aircraft was more than counterbalanced by image compression due to the orientation of the focal plane shutter. The compression was theoretically 1.39% compared to the observed 0.77%. We oriented our camera so that the focal plane shutter moved from right to left; theoretically almost no distortion would occur either along the axis of flight or perpendicular to it. In our case, maximum distortion would occur when the whale or target was oriented 45° to the line of flight and the magnitude of maximum distortion would be only 71% (cosine 45°) of the distortion observed when the focal plane shutter moves from front to back or back to front of the aircraft. Because of the orientation of our targets relative to our line of flight we were not able to quantify distortion due to movement of the focal plane shutter.

Measurements of Known-Length Targets

To quantify potential sources of error, seven vertical and seven horizontal measurements were taken from each of 80 photographs of our calibration target (Plate 1). Measurements were made along the axis of movement of the aircraft (called 'length' here), and perpendicular (called 'width' here) to this axis. The actual lengths of segments of the target were 1.00, 3.00, 4.00, 7.00, 10.00, 15.00 and 20.00 m. The measurements from the photographs were then compared to the actual dimensions of the target segments. The calculated lengths and widths were decreased by the vertical components of 0.103 m (with a shutter speed of 1/500 s) or 0.051 m (with a shutter speed of 1/1000 s) to account for image elongation due to forward movement of the aircraft. In Plate 1 the arrow indicates the direction of the flight path of the aircraft. The vertical elongation is calculated to be 0.103 cosine θ and the horizontal elongation is 0.103 cosine $(90-\theta)$.

The calculated measurements (adjusted for image elongation) of the seven different target lengths are summarized for each day in Table 17. The frequency distributions of the length and width measurements are presented in Figure 30. The pilot on days 1, 2 and 3 was Brian McKinley, who was also the pilot for our photographic flights during 1981 and 1982. The pilot on day 4 was John Brecken who was newly trained in the photographic procedures during 1984. On days 1 and 2, photographic sessions were conducted at an abandoned DEW and, later, oil exploration site at BAR C in the Mackenzie Delta, on day 3 at the abandoned BAR B DEW site at Stokes Point, and on day 4 at a currently occupied DEW site at Shingle Point. On each of days 1, 2 and 3, five photographs were taken with each of two cameras at shutter speeds of 1/500 and 1/1000 sec for a total of 20 photographs of the target on each day. Camera 2 malfunctioned before day 4. On Day 4, 10 photographs were taken at each shutter speed using the remaining camera.

It should be noted that, on days 1 and 2, winds were estimated to be 35-40 and 25 km/h, respectively, and turbulence was experienced while we photographed the target. Conditions were much more turbulent at these times than they were during any of the whale photography sessions. Although the mean measurements for days 1 and 2 are similar to those for days 3 and 4 (see Table 17) the measurements obtained on days 1 and 2 were more variable than those obtained on other days (standard deviations for the 15 m measurements for day 1 = 0.157 m, day 2 = 0.169 m, day 3 = 0.124 m and day 4 = 0.112 m).

The following sections examine several potential sources of error. The analyses were performed on the 15 m measurements unless otherwise stated.

Table 17. Mean length and width measurements calculated from a measured calibration target that was photographed 20 times on each of four separate days, August-September 1984.

Actual Measurement		Mean Calculated Measurement (m)	
	Day*	Length	Width
1.00 m			
	1	0.985	1.008
	2	0.966	1.015
	3	0.976	0.989
	4	0.936	1.001
3.00 m			
	1	2.95	2.96
	2	2.91	2.98
	3	2.94	2.94
	4	2.87	2.95
4.00 m			
	1	3.93	3.94
	2	3.89	3.97
	3	3.91	3.92
	4	3.83	3.92
7.00 m			
	1	6.86	6.87
	2	6.81	6.91
	3	6.86	6.85
	4	6.74	6.84
10.00 m			
	1	9.78	9.78
	2	9.73	9.84
	3	9.79	9.78
	4	9.63	9.76
15.00 m			
	1	14.64	14.65
	2	14.59	14.70
	3	14.69	14.66
	4	14.48	14.62
20.00 m			
	1	19.45	19.50
	2	19.44	19.54
	3	19.58	19.53
	4	19.33	19.45

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* Day 1 = 19 August at BAR C, Day 2 = 28 August at BAR C, Day 3 = 2 September at Stokes Point, and Day 4 = 12 September at Shingle Point.

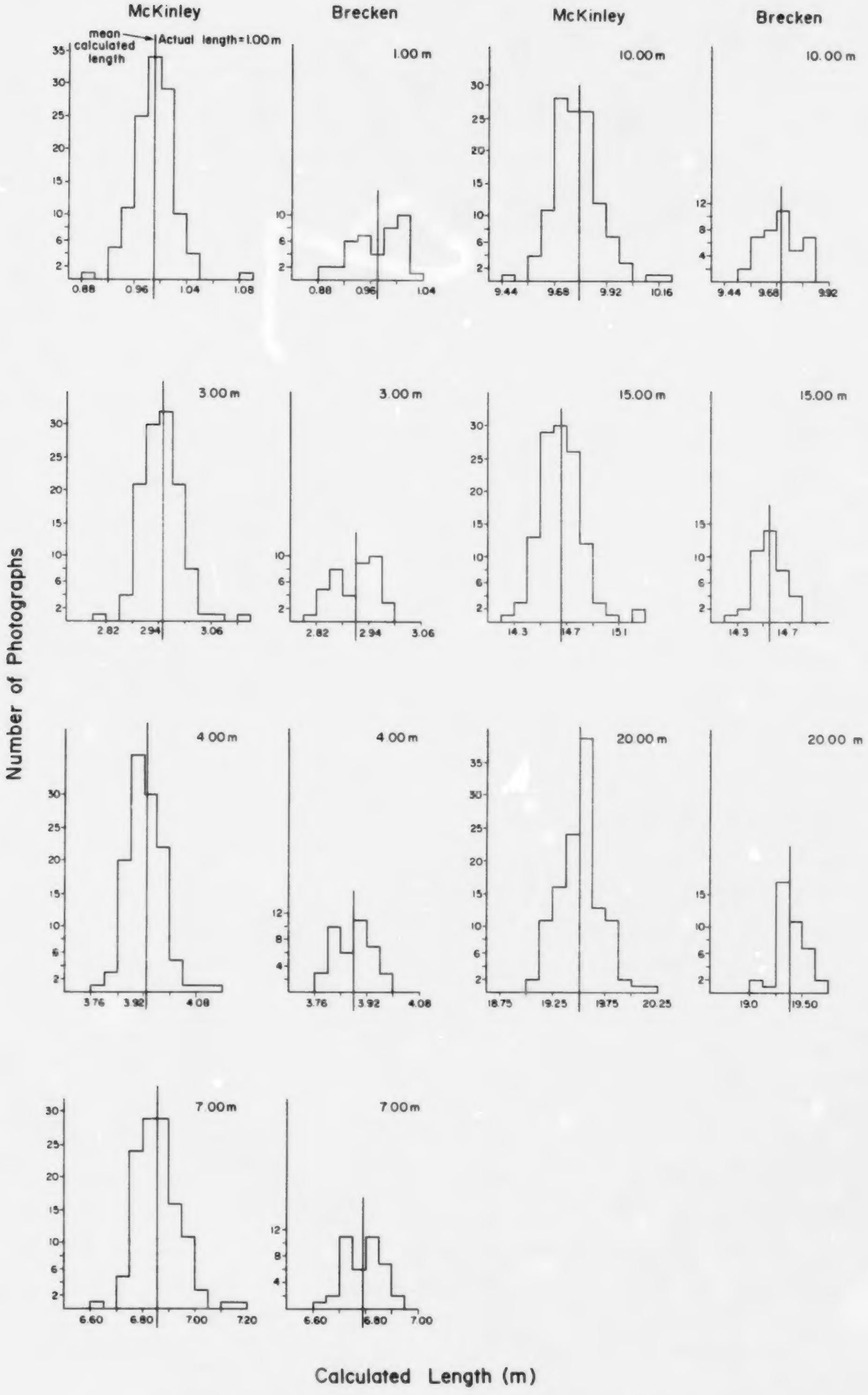


Fig. 30. Frequency distribution of estimated length and width measurements calculated for the calibration target, based on overflights conducted by each of two pilots in 1984. Estimates are corrected for image elongation.

Camera Effects

The first analysis examined the effects of using two different cameras to obtain photographs. Day 4 was excluded because only one camera was operational at that time. There were no significant differences between measurements from photographs taken using the two different cameras either before (one-way ANOVA; $F = 0.16$, $P = 0.688$, df = 1,118) or after measurements were adjusted for forward motion ($F = 0.25$, $P = 0.624$, df = 1,118).

Shutter Speed Effects

When data that had not been corrected for forward elongation were examined, the measurements were significantly different between photographs shot at shutter speeds of 0.002 and 0.001 sec (one-way ANOVA; $F = 4.97$, $P = 0.025$, df = 1,158). However, after data were corrected for image elongation, this difference disappeared ($F = 1.80$, $P = 0.178$, df = 1,158).

Pilot Effects

The timing and duration of the 1984 study necessitated the use of two pilots. Estimated sizes of the calibration target were significantly different when different pilots flew the aircraft, considering either corrected (one-way ANOVA; $F = 16.67$, $P = 0.0002$, df = 1,158) or uncorrected measurements ($F = 17.35$, $P = 0.0002$, df = 1,158). Although this difference is statistically highly significant, the mean difference between pilots for the 15 m target measurement was only 10.7 cm or about 0.7%.

This difference appeared to be due to the two pilots' flying the aircraft at slightly different pitches without the photographer compensating for the change (the photographer attempted to maintain the same techniques and procedures throughout the project). Neither length nor width measurements were significantly different among days when McKinley piloted the aircraft, whether or not measurements were corrected to account for forward motion (one-way ANOVA, corrected data: $F = 1.50$, $P = 0.191$, df = 5,114; uncorrected data: $F = 1.30$, $P = 0.266$, df = 5,114). When Brecken piloted the aircraft, uncorrected lengths were marginally different than widths (ANOVA, F = 6.23, P = 0.0162, df = 1,38) and corrected lengths were significantly different than widths (F = 24.45, P = 0.0001, df = 1,38). Additionally, there were no significant differences among width measurements during the four days of photographing targets (ANOVA, corrected data, F = 1.148, P>0.25, df = 3,76). This suggests that photographs from Brecken's flights were very slightly oblique in the direction of aircraft movement but not to the left or right of it. Despite this bias, the combined length and width measurements for the 15 m sections of the target were less variable when Brecken piloted the aircraft (coefficient of variation = 0.77%) than when McKinley piloted the aircraft (coefficient of variation = 1.04%). This was probably due to the increased variability in measurements caused by the windy conditions on days 1 and 2, as mentioned earlier.

Variability

The repeatability and reliability of the target measurements increased with length (Tables 18 and 19). Although the data from the turbulent sessions on 19 and 28 August are included, these tables indicate that measurements of objects 7 to 15+ m long should be accurate to ± 3.0% more than 99 times out of 100. This is very similar to our 1982 results (Davis et al. 1983). Our measurements over water were probably less variable than

Table 18. Calculated measurements (m) of a calibration target photographed 20 times on each of 19 and 28 August and 2 September 1984. Corrected for image elongation.

Actual length	Calculated measurement (± s.d.)	99% Confidence interval (s.d. x 2.58)	99% Confidence interval as % of calculated measurement	Coefficient of Variation
1.00 m	0.99 ± 0.030 m	± 0.077 m	± 7.82%	3.03%
3.00	2.95 ± 0.045	± 0.116	± 3.94	1.53
4.00	3.93 ± 0.054	± 0.139	± 3.55	1.37
7.00	6.86 ± 0.081	± 0.209	± 3.05	1.18
10.00	9.78 ± 0.108	± 0.279	± 2.85	1.10
15.00	14.66 ± 0.153	± 0.395	± 2.69	1.04
20.00	19.51 ± 0.204	± 0.526	± 2.70	1.05

Table 19. Calculated measurements (m) of a calibration target photographed 20 times on 12 September 1984. Corrected for image elongation.

Actual length	Calculated measurement (± s.d.)	99% Confidence interval (s.d. x 2.58)	99% Confidence interval as % of calculated measurement	Coefficient of Variation
1.00 m	0.97 ± 0.039 m	± 0.101 m	± 10.37%	4.02%
3.00	2.91 ± 0.051	± 0.132	± 4.52	1.75
4.00	3.88 ± 0.056	± 0.144	± 3.72	1.44
7.00	6.79 ± 0.073	± 0.188	± 2.77	1.08
10.00	9.70 ± 0.088	± 0.227	± 2.34	0.91
15.00	14.55 ± 0.112	± 0.289	± 1.98	0.77
20.00	19.39 ± 0.130	± 0.335	± 1.73	0.67

those of the target because we did not take any whale photographs during conditions as turbulent as those during the 19 and 28 August calibration sessions, which are included in Table 18.

Correction Factors

Mean calculated lengths for each section of the calibration target underestimated the actual lengths (Table 18, 19). To account for this underestimation, correction factors were developed using the data from the target measurements. Strong linear relationships were found to exist between mean calculated lengths and true lengths for all data sets examined.

Two sets of correction factors were calculated because the calculated lengths based on data from the two pilots were significantly different. In addition, separate correction factors were developed for correcting whale lengths (using data for the 4 to 20 m sections of the target), and for snout-to-blowhole and fluke width measurements (using data for the 1 to 7 m sections).

The calculated length of each whale photographed with McKinley as the pilot was corrected using the following equation:

$$\text{Actual Length} = (\text{Calculated Length} - 0.040)/0.9738$$

This equation was rearranged from the regression equation

$$\text{Calculated Length} = 0.040 + 0.9738 \text{ Actual Length}$$

($r^2 = 1.00$, $F = 816022$, $P<0.001$). The slope of the line obviously differs from zero. The calculated snout-to-blowhole lengths and fluke widths based on photographs taken with McKinley as the pilot were corrected using the following equation:

$$\text{Actual Measurement} = (\text{Calculated Measurement} - 0.012)/0.9783$$

For photographs taken when Brecken was the pilot, calculated whale lengths were corrected using the equation

$$\text{Actual Length} = (\text{Calculated Length} + 0.0001)/0.9698$$

Calculated snout-to-blowhole lengths and fluke widths were corrected using the equation

$$\text{Actual Measurement} = (\text{Calculated Measurement} + 0.002)/0.9701.$$

Measurements of Re-identified Whales

Whitehead and Payne (1981) and Davis et al. (1983) have discussed the magnitude of errors in length measurements that can be attributed to the posture of the whale at the time of photography. These errors would not be present in the photography of our targets. To assess the net impact of all potential sources of error, we compared our measurements of whales that were photographed more than once. The best overall assessment of the methods is obtained by comparing measurements of the same whale derived from different photographs. The degree to which the different estimates agree is the degree to which the technique can provide repeatable measurements.

During the present study, 123 different whales were rephotographed at least once and were identified without knowledge of the length of the whale. Rephotographs of an additional 13 whales were later identified with the aid of length measurements. These latter whales are excluded from this analysis, which compares the length estimates of re-identified whales. (Measurements of re-identified whale are given in Data Appendix 1.)

The 123 whales were identified on 307 images. Thus, each rephotographed whale was photographed an average of 2.50 times. At least one estimate (grade 1-6) of length was obtained for 109 (89%) of the 123 whales.

Initially, mean length was calculated for each of the 61 whales for which there was one measurement of grades 1-4 plus at least one other measurement. Deviations from means were calculated for each grade shown at the top of Table 20. Both grade 5 and grade 6 measurements compared favorably with grade 4 measurements with respect to the sizes of deviations from mean lengths. However, when the direction of the difference was considered, grade 5 measurements consistently underestimated mean lengths. In order to increase the sample sizes, we included grade 6 measurements in the calculation of means. This increased the number of individual comparisons from 87 to 121 (excluding grade 5 and projected lengths).

Using this enlarged data set, the mean deviation between each calculated length and the mean length for that whale was 1.27% (Table 20-B). As expected, grade 1 lengths had the smallest average variation from mean lengths (0.73%) and grades 2 (1.10%) and 3 (1.17%) had only slightly larger average variations from mean lengths. Unexpectedly, grade 6 lengths, which are estimates of length rather than actual measurements, had an average variation from mean lengths of only 1.37%, whereas the average variation for grade 4 measurements was 1.53%.

Lengths estimated from grade 5 images, which were arched and flexed whales, had a mean deviation of 2.65% from mean length. When the direction of the difference was considered, grade 5 values underestimated mean lengths by 1.85%. If each of these grade 5 values is increased by 1.85% and is included in the calculations of mean lengths, the % variation of the "corrected" grade 5 values relative to the mean is reduced from 2.65% to 1.20% (n = 12, range = +3.01 to -3.42). Thus, data from arched and flexed whales, if corrected for the underestimation of length due to the arching or

Table 20. Comparisons of measurements of re-identified whales according to the measurement grade of each whale image. For each whale, the measurements from different photographs were averaged to determine the mean length of the whale. The tabulated numbers represent the average percentage variation from the mean measurements for all photographs of the respective measurement grades without respect to the direction (+ or -) of difference. Grade 5 measurements and lengths projected from SB and FW measurements were not included in calculating mean lengths but have been compared to mean lengths to illustrate their accuracy relative to other grades of measurements.

	Grade of Measurement							
Measurement Type	1	2	3	4	5*	6	Projected from SB and FW	All Grades Used to Calculate Mean
A - Means calculated using Grades 1, 2, and 3 data								
LENGTH	0.67**	0.96	0.92	NOT COMPARED				n = 49 0.89
FLUKE WIDTH	N/A***	1.63	1.75	NOT COMPARED				n = 30 1.58
SNOUT-TO-BLOWHOLE	N/A	N/A	2.39	NOT COMPARED				n = 12 3.63
B - Means calculated using Grades 1, 2, 3, 4 and 6 data								
LENGTH	0.73	1.10	1.17	1.53	2.65	1.37	8.16	n = 121 1.27
FLUKE WIDTH	N/A	1.49	1.87	2.26	N/A	N/A	N/A	n = 46 1.74
SNOUT-TO-BLOWHOLE	N/A	N/A	3.39	N/A	N/A	N/A	N/A	n = 18 4.33

* Grade 5 includes only animals that were severely arched, flexed, or had their tails bent up or down.

** Mean % variation of a particular measurement from the mean for that whale.

*** Mean % variation is not shown if fewer than 8 duplicate measurements were compared.

flexing (approx. 1.85%) appear to be reasonable estimates of the whales' actual length. Corrected grade 5 data have been used in parts of this report.

Lengths projected using snout-to-blowhole and fluke width measurements had an average deviation from the mean length of 8.16%, and overestimated mean lengths by an average of 6.18%. The average percentage variation from the mean measurement was much larger for fluke width and snout-to-blowhole measurements than for measured lengths (Table 20). This is due in part to the larger percentage variation that occurs when measuring small objects (Tables 18, 19) and to the difficulty in determining precisely the extremities of whales in turbid water. The latter problem was more pronounced in our 1984 than our 1982 photographs and it was most evident in the 1984 snout-to-blowhole comparisons.

When only grade 1-3 data were used in the comparisons, average deviations from mean measurements declined in all cases except one (Table 20). The overall average percentage deviation of grade 1-3 values from mean length measurements was 0.89%. This is lower than in our 1982 study when the average percentage deviation for length measurements of grades 1-3 was 1.14%. It appears that the experience obtained in conducting the photography and classifying the posture of whales in 1982 permitted us to make more accurate estimates of whale lengths and to better assess biases due to whale posture during the present study.

Snout-to-Blowhole Distance vs. Whale Length

Both whale length and snout-to-blowhole distance were determined for 86 whales with data of grades 1-6 (Fig. 31). As in previous studies, a significant linear relationship was found to exist between the length of the whale and the horizontal projection of the snout-to-blowhole distance ($F = 986.8$, $P \ll 0.001$, $r^2 = 0.92$).

The relationship is described by the equation

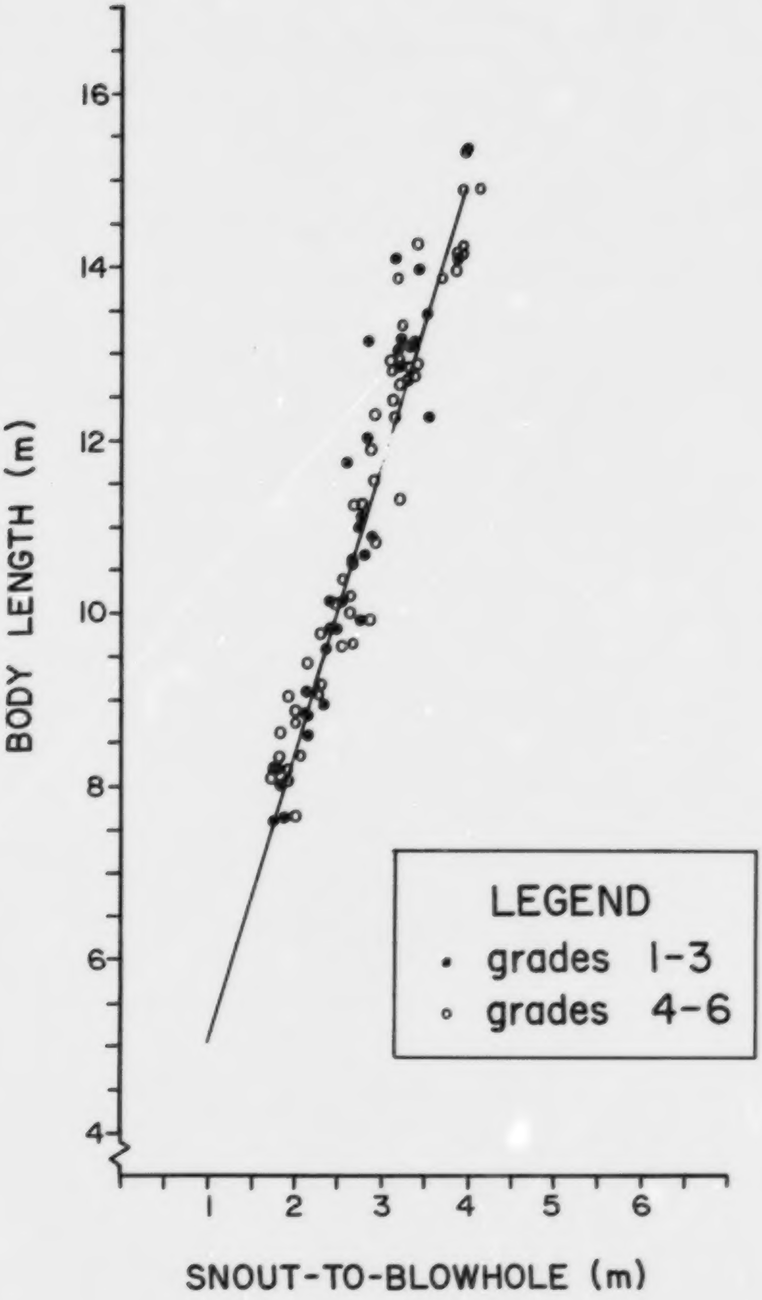


FIG. 31. Length vs. snout-to-blowhole distance for bowhead whales photographed in the Canadian Beaufort Sea, August-September 1984.

Length = 2.219 + 3.183 Snout-to-Blowhole Distance

This equation is virtually identical to the equations of Davis et al. (1983) (L = 2.386 + 3.291 SB) and Cubbage et al. (1984) (L = 2.15 + 3.35 SB).

Inclusion of only measurements of grades 1-3 and mean measurements from duplicate photographs reduced the number of whales included in the analysis to 33 ($F = 291.9$, $P<0.001$, $r^2 = 0.90$) and resulted in the equation

Length = 1.617 + 3.403 Snout-to-Blowhole Distance.

Fluke Width vs. Whale Length

Both whale length and fluke width measurements of grades 1-6 were obtained for 107 whales (Fig. 32). As with the snout-to-blowhole data, a significant linear relationship was found to exist between whale length and fluke width ($F = 944.8$, $P<<0.001$, $r^2 = 0.90$). This relationship is described by the equation

Length = 1.821 + 2.371 Fluke Width.

When only grades 1-3 and mean measurements from duplicate photographs were included, the number of whales included in the regression was reduced to 62 ($F = 515.9$, $P<<0.001$, $r^2 = 0.90$). Although the r^2 value was the same, the slope and intercept changed somewhat:

Length = 2.452 + 2.205 Fluke Width.

The first equation closely approximates the equation of Davis et al. 1983 (L = 1.899 + 2.355 FW). The difference between the two regressions based on different grade data suggests that fluke-width measurements of poor grades tended to underestimate the actual fluke width for large whales and overestimate the actual fluke width for smaller whales.

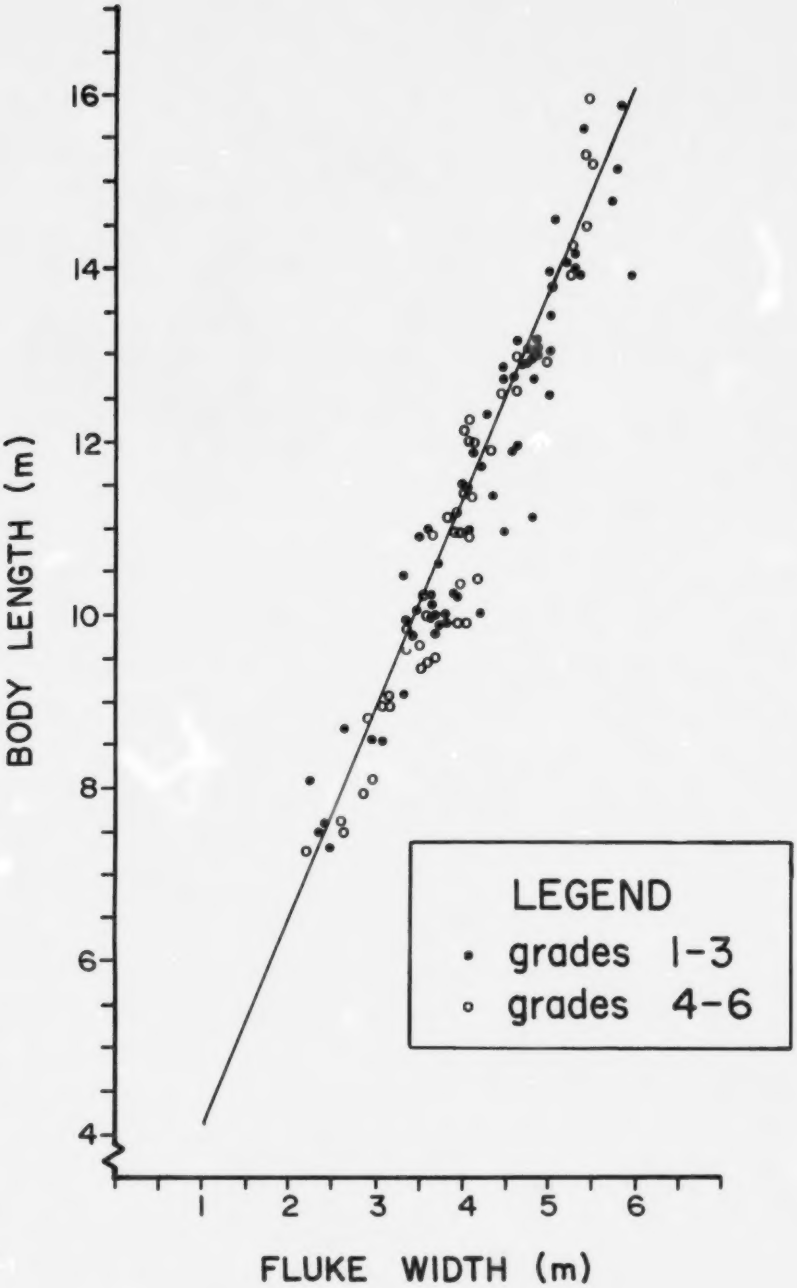


FIG. 32. Length vs. fluke width for bowhead whales photographed in the Canadian Beaufort Sea, August-September 1984.

APPENDIX 2

ANALYSES OF MEASUREMENTS OF BOWHEAD WHALES

Numbers and Types of Measurements

During this study, 1114 whale images were obtained. Many of these images were of whales in turbid water where only a snout, the tip of a fluke, or a portion of the back of a whale was visible. These images were not suitable for measurements. Usable length measurements (which include only grades 1-6) were obtained for 488 (44%) of the images obtained and grade 1-4 lengths were obtained for 330 (30%) (Table 21). In addition, usable snout-to-blowhole measurements were obtained from 151 images and usable fluke width measurements were obtained from 182 images. We used the data from whales for which we had a usable length measurement and either a snout-to-blowhole or a fluke width measurement to determine the relationship between the latter two measurements and total length (see Appendix 1). Using the relationships that were established, we were able to determine approximate lengths for whales that had snout-to-blowhole or fluke width measurements but no length measurements. These are the whales identified as projections in Table 21. Therefore, when lengths from all available sources are included, some estimate of length could be determined for 669 (60%) of the images that were obtained.

In 1982, grade 1-4 length measurements were obtained for 60% of the photographic images, and one measurement of any grade was obtained for 84% of the images (Davis et al. 1983). The lower success in measuring whales in 1984 compared with 1982 was attributable to two factors. The primary objective of the 1982 study was to determine the lengths of as many whales as possible; therefore, whales in muddy water were not photographed and the same area was not repeatedly photographed. In this study we attempted to photograph whales that were closest to industrial activity; most of these whales were in muddy water. We also photographed in and around areas previously photographed in an attempt to re-identify whales. These constraints resulted in much of the photography being conducted in areas with muddy waters or high sea states, which would have been avoided in 1982.

Table 21. Numbers of whale images for which length estimates of various quality were determined during 1984 aerial photography surveys. If a grade 1, 2, 3, 4, 5 or 6 measurement was not available from an image, the best quality projection was tabulated. An indirect measurement of grades 1-6 was assumed to be better than a projected length.

Measurement Grade	Length of Whale										Total	Mean Length ± s.d.
	<7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16		
Direct Measurements												
1	0	1	1	1	0	2	5	7	1	1	19	12.55 ± 2.01
2	0	1	9	8	8	6	7	6	1	3	49	11.16 ± 2.09
3	3	5	13	15	23	11	9	14	9	5	107	11.11 ± 2.29
4	3	9	20	25	27	16	25	18	10	2	155	10.97 ± 2.13
5	0	5	9	15	10	4	5	5	4	0	57	10.47 ± 1.98
6	0	4	12	23	16	11	12	16	6	1	101	11.00 ± 2.02
Total "Usable" Measurements	6	25	64	87	84	50	63	66	31	12	488	
Fluke Width Projections	0	2	6	5	9	8	5	1	1	1	38	10.66 ± 1.84
Snout-To-Blowhole Projections	0	2	8	11	10	10	6	7	2	1	57	10.91 ± 1.92
Indirect Measurements*												
1-6	4	0	4	13	16	11	8	14	7	0	77	11.31 ± 2.12
Fluke Width or Snout-To-Blowhole Projections	0	1	2	3	1	1	0	0	1	0	9	10.00 ± 2.01
TOTAL IMAGES WITH ANY TYPE OF LENGTH MEASUREMENT	10	30	84	119	120	80	82	88	42	14	669	

---

* The lengths of these whales could not be determined from the actual photograph but the lengths were determined from another photograph of the whale.

Thus, larger numbers of photographs were obtained in 1984 because we returned to areas where whales had been seen previously, but the overall quality of the photographs was lower.

Length-frequency Distribution

The overall length frequency distribution of whales photographed during the summer of 1984 is presented in Figure 33. This histogram contains all of the 488 measurements (including duplicates) of grades 1-6 (Table 21). Because it is clear that there was differential distribution of various age classes of bowheads, the data in Figure 33 do not represent the length distribution of the whole population.

The largest whale measured was 15.98 m and the smallest was 5.82 m. The largest whale photographed in 1984 was considerably smaller than the largest whale photographed in 1981 (17.6 m, Davis et al. 1982), 1982 (16.6 m, Davis et al. 1983) or 1983 (17.6 m, Cubbage et al. 1984).

Photographability of Whales

There is the potential that whales of different size classes may have reacted in different ways to the approaching aircraft. For example, smaller (= younger) animals may have been less familiar with aircraft disturbance and may have begun to take evasive action as the aircraft approached. Related to this, it is possible that large, experienced whales are less likely to respond to aircraft. If this were true, we would expect the average length of arched, flexed and inclined whales (grade 5) and whales with lengths determined by projecting lengths from fluke-width measurements to be smaller than that of grades 1-4 and 6 whales (Table 21).

Our 1982 data indicated that we were more likely to obtain grade 1 measurements of large whales (Davis et al. 1983). The mean size of grade 1 measurements in 1984 (12.55 m, Table 21) was again larger than the means for all other grades. In addition, mean whale lengths determined from grade 5 measurements (10.47 m) and fluke width measurements (10.66 m) were slightly smaller than other measurements. However, when the frequency distributions

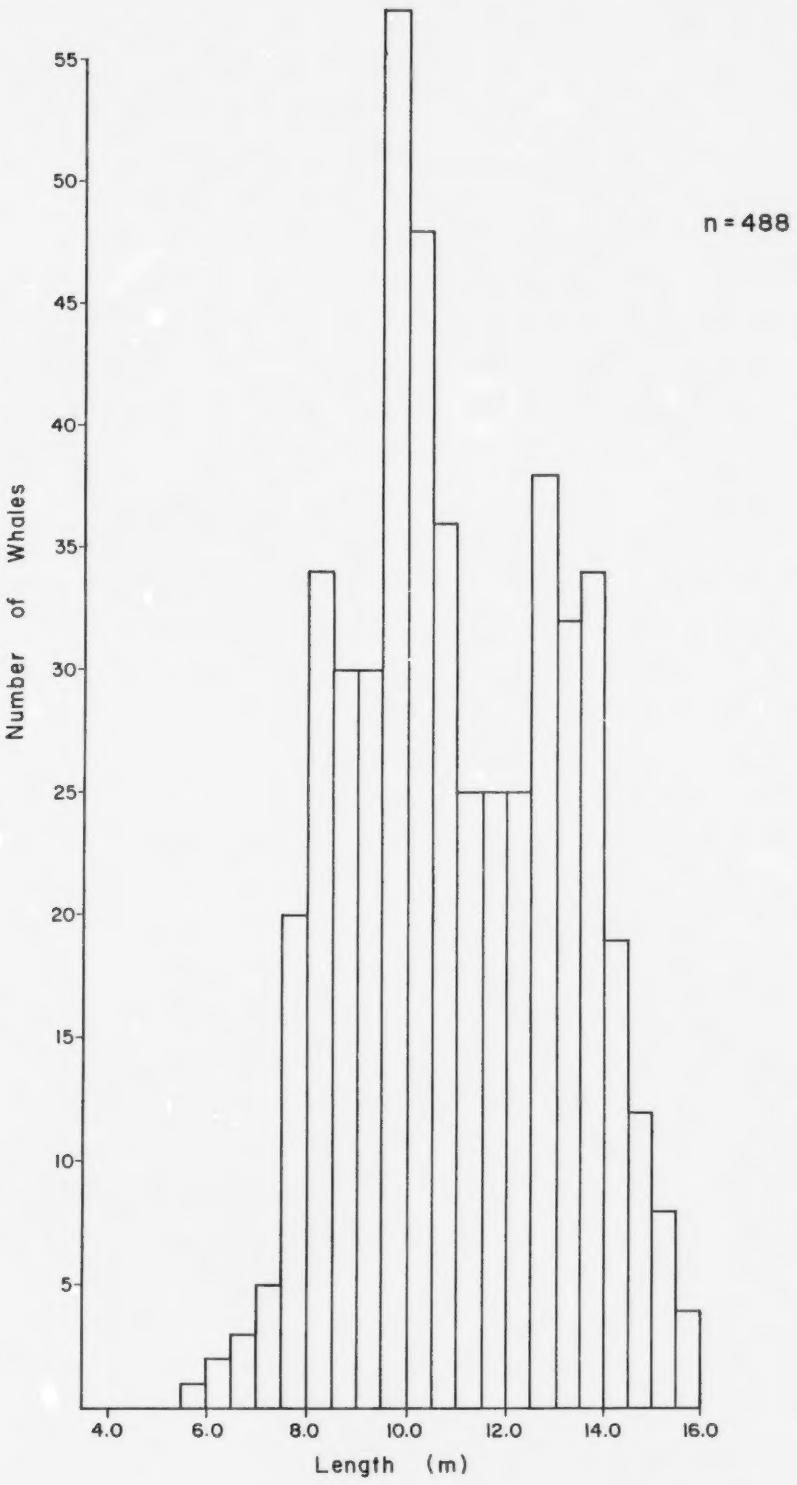


FIG. 33. Length-frequency distribution (repeated measurements included) of bowhead whales photographed in the Canadian Beaufort Sea, 14 August-14 September 1984.

of whale lengths calculated from grades 1-6 and fluke width measurements were compared (Table 21), no significant differences were found (G test; $G = 48.20$, $df = 42$, $P>0.05$). Thus any tendency for the numbers of small whales to be underestimated in our length frequency distribution is very weak or has been reduced because few larger whales were photographed in 1984.

Repeat Measurements

The length-frequency distribution in Figure 33 contains whales that were measured more than once. In order to interpret histograms from which these "duplicate" measurements have been removed, it is necessary to determine whether the probability of re-identifying a measurable whale varies with its length. The length-frequency distribution of whales that were measured more than once is shown in Figure 34-A. When this distribution is compared to Figure 33 it can be seen that whales of different sizes are not equally likely to be re-measured. Although whales larger than 13.0 m made up only 22% of all images with usable measurements, they formed 38% of the identified repeated measurements and 37% of the individual whales with repeated measurements (Table 22; Fig. 35). The frequency of repeated measurements

Table 22. Numbers of repeated measurements in relation to the length of the whale, Canadian Beaufort Sea, 14 August-14 September 1984.

Size Class (m)	All Measurements (Fig. 33)	All Measurements Excluding Repeats (Fig. 35)	All Measurements of Re-identified Whales (Fig. 34-A)	Single Measurements of Each Re-identified Whale (Fig. 34-B)
>13.0	109 (22)*	72 (18)	63 (38)	26 (37)
9.01-13.00	284 (58)	231 (59)	88 (53)	35 (50)
7.51-9.00	84 (17)	78 (20)	14 (8)	8 (11)
<7.51	11 (2)	10 (3)	2 (1)	1 (1)
Total	488	391	167	70

* Percent of column total.

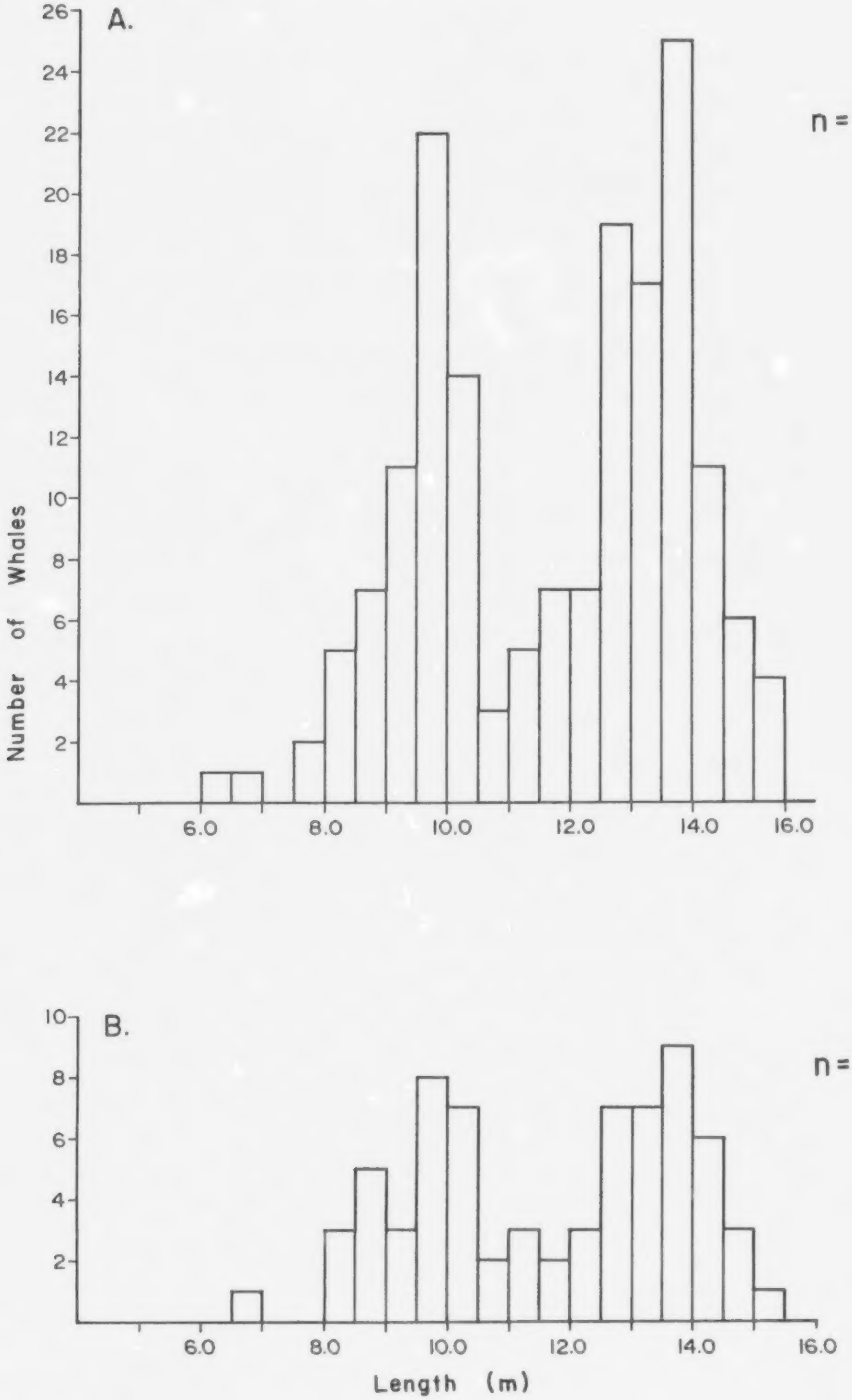


FIG. 34. Lengths of bowhead whales that were measured more than once during 1984. A includes each measurement of a whale measured more than once. B includes only one measurement for each whale. This is the average of all usable length measurements.

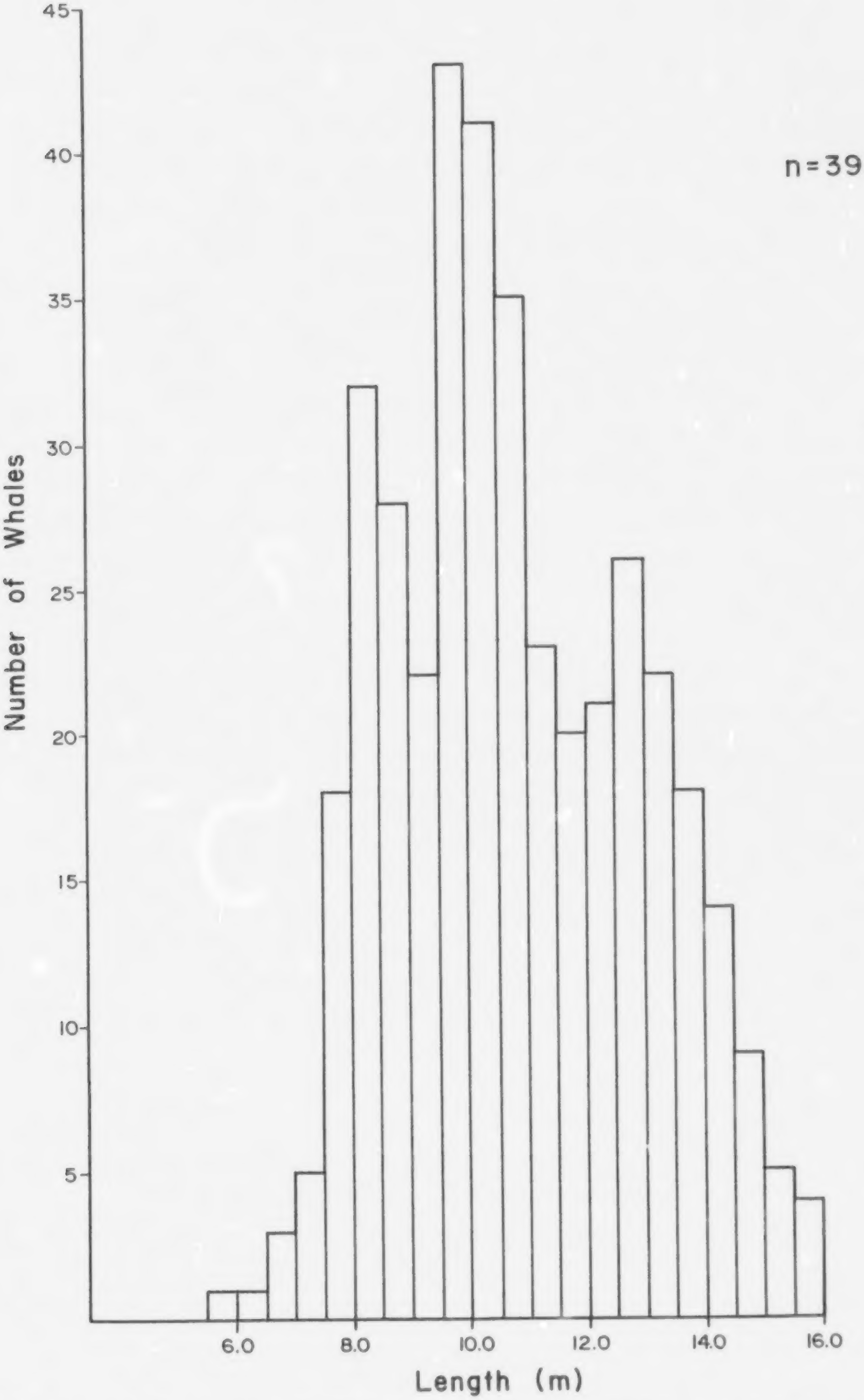


FIG. 35. Length-frequency distribution (repeated measurements averaged) of bowhead whales photographed in the Canadian Beaufort Sea, 14 August-14 September 1984.

differed very significantly among the different size categories ($\chi^2 = 13.27$, df = 3, $P<0.01$). Thus, numbers of smaller whales are overestimated in frequency distributions from which repeated whale measurements have been removed (Fig. 35 vs. 33).

Inter-year Comparison of Numbers of Repeated Measurements

Table 23 shows, for both 1982 and 1984, the number and percentage of measured whales in different size classes that had repeated measurements. The overall percentages of whales with more than one usable length measurement were not significantly different in 1982 (16%) and 1984 (18%; $\chi^2 = 0.55$, df = 1, $P>0.30$). Although the percentage of repeats among whales >13.0 m was higher in 1984 than in 1982, the difference was not significant ($\chi^2 = 0.75$, df = 1, $P>0.30$).

Our efforts to photograph individual groups of whales on a particular day were conducted in a similar way in 1982 and 1984, with one notable exception. On 2 September 1984 we remained over a group estimated to contain approximately 20 whales for a prolonged period and took about twice the number of photographs that we would normally have attempted. Because of this

Table 23. Proportion of whales, in various length categories, for which we have repeated measurements in 1982 and 1984.

	1982		1984		1984*	
Size Class	Number of Whales (Repeats Removed)	Number With Repeated Lengths (%)	Number of Whales (Repeats Removed)	Number With Repeated Lengths (%)	Number of Whales (Repeats Removed)	Number With Repeated Lengths (%)
>13.0 m	122	34 (28)	72	26 (36)	58	15 (26)
9.01-13.00 m	184	18 (10)	231	35 (15)	222	30 (14)
7.51-9.00 m	13	0 (0)	78	8 (10)	78	8 (10)
<7.51 m	42	4 (10)	10	1 (10)	10	1 (10)
Total	361	56 (16)	391	70 (18)	368	54 (15)

* Excluding whales photographed in the North Industrial Zone on 2 September.

prolonged session we obtained repeated length measurements for 16 of the 23 (70%) whales that we later identified from the photographs. The last two columns in Table 23 give the data when the photographs taken during this session are excluded. There is still no significant between-year difference in the overall percentages of repeated measurements ($\chi^2 = 0.07$, df = 1, $P>0.70$). Also, the percentage of large whales (>13.0 m) for which we obtained repeated length measurements in 1984 declines to 26%, which is very similar to the 28% recorded in 1982 (Table 23).

Unrecognized Repeated Measurements

It is reasonable to assume that whales of different lengths are equally likely to be photographed. Although there is a slight tendency for smaller animals to be more difficult to measure and for larger animals to be slightly easier to measure (see preceding sections), we assume here that all animals over 7.5 m in length are equally measureable. We have also excluded data from the 2 September session because the extra effort expended on this date seriously biases the proportion of larger whales with duplicate length measurements. The available evidence suggests that large whales (>13 m) are most likely to be well marked and scarred. Therefore, few repeated photos of large whales are likely to go unrecognized as repeats. Smaller size categories are likely to contain higher proportions of unrecognized repeats because smaller animals are less well-marked. If we apply the ratio of repeat to total photos obtained for large animals to the smaller size categories, we should be able to estimate the number of unrecognized repeat measurements in these groups.

For animals over 13.0 m in length, we obtained 79 measurements of which 58 (73.4%, Table 24) were measurements of a whale not previously measured. If we assume that 73.4% of the measurements in each of the other length categories represent whales not previously measured, there are 195 unique whale measurements in the 9.01 to 13.00 m category and 62 in the 7.51 to 9.00 m category. The differences between these latter numbers and column B in Table 24 represent the estimated numbers of undetected repeated whale lengths in the histogram in Figure 35. Thus, there are about 29 undetected repeated values from 9.01 to 13.00 m, and 14 from 7.51 to 9.00 m (Table 24).

Table 24. Undetected repeats in the frequency distribution using length information, 1984. Data from 2 September have been excluded because they bias estimates of the proportion of larger whales for which there were repeated measurements (see text).

Size Class	Overall Number of Measurements (A)	Measurements Excluding Repeats (B)	Proportion B/A	Expected Unique Measurements* (A x .734)	Undetected Repeat Whales
>13.0 m	79	58	.73	58	0
9.01-13.00 m	265	224	.85	195	29
7.51-9.00 m	84	76	.90	62	14
Total	428	358	.84	315	43

* Assuming that 73.4% of all measurements are unique.

APPENDIX 3

BASIC PHOTO-IDENTIFICATION ANALYSES

We obtained a total of 1114 photographic images of whales during the 1984 field season. Custom 5 x 7" enlargements were printed of 1085 (97.4%) of these images. We recognized 340 of these printed images to be repeated photos of a total of 136 different whales. Of the remaining 745 printed images, 137 were judged to be unlikely to be recognizable if re-photographed (i.e. grade C). Thus, we obtained multiple images of 136 individuals and single images of an additional 608 potentially recognizable whales or a total of 744 different whales.

The prints were sorted and filed into categories based on the amount of white on the lower jaw (4 categories) and on the fluke/caudal region (3 categories). The categories were defined by reference to standard photographs (Davis et al. 1983). The 12 categories formed the basis of our photo-identification key (Braham and Rugh 1983). In total, 375 printed images representing a maximum of 239 different whales were classified according to the 12 categories. The remaining prints were filed in other categories because the snout and/or tail were not clearly discernible.

The distribution of the 375 prints among the 12 different file categories is shown in Table 25. The amounts of white coloration on the lower jaw and in the fluke/caudal region were not independent ($\chi^2 = 28.29$, df = 6, $P<0.001$). This result was unexpected because analysis of our 1982 data (n = 453) indicated that there was no relationship between the amount of white coloration on the lower jaw and in the fluke/caudal region. A test of the pooled data from the two years (n = 828) was consistent with the 1984 result ($\chi^2 = 21.21$, df = 6, $P<0.01$).

White Pigmentation as a Function of Whale Length

Our 1982 study (Davis et al. 1983) indicated that well-marked whales were not evenly distributed among the various size categories in the population. To assess this question for the 1984 data, we examined the length distributions of the 375 images that could be assigned to one of the

Table 25. The relationship between the amount of white on the lower jaw and in the fluke/caudal region of bowhead whales, Canadian Beaufort Sea, 14 August-14 September 1984. (Repeat photos are included.)

Amount of white on lower jaw	Amount of White in Fluke/Caudal Region						Total
	Extreme		Moderate		None		
	File	Number (%)	File	Number (%)	File	Number (%)	Number (%)
Extreme	1	11 (3)	2	14 (4)	3	20 (5)	45 (12)
Large	4	28 (7)	5	24 (6)	6	96 (26)	148 (39)
Moderate	7	7 (2)	8	34 (9)	9	47 (13)	88 (23)
Small	10	11 (3)	11	15 (4)	12	68 (18)	94 (25)
Total		57 (15)		87 (23)		231 (62)	375 (100)

12 primary files in which both snout and fluke/caudal region could be clearly seen. Eliminating 136 prints that represented photos of previously photographed whales, there remained 239 prints of different whales, of which 220 had usable (grades 1-6) length measurements.

Lower Jaw

The length-frequency distributions of whales in the four categories of jaw colouration are plotted in Figure 36. The four distributions (see Table 26) do not differ significantly (χ^2 = 12.11, df = 12, P>0.30). The median lengths of whales in the four categories were 10.6 m for the category with little or no white on the lower jaw and 11.3 to 12.5 m for the other three categories (Fig. 36). In an earlier report (Davis et al. 1983), we considered whales over 13 m in length to be potentially breeding adults. The relative numbers of adults and immatures differed among the four lower jaw categories (χ^2 = 8.33, df = 3, P<0.05). The proportion of adults was similar in the three jaw categories containing the most white (28 to 38%). However, the proportion of adults in the category with little or no white was only 13%

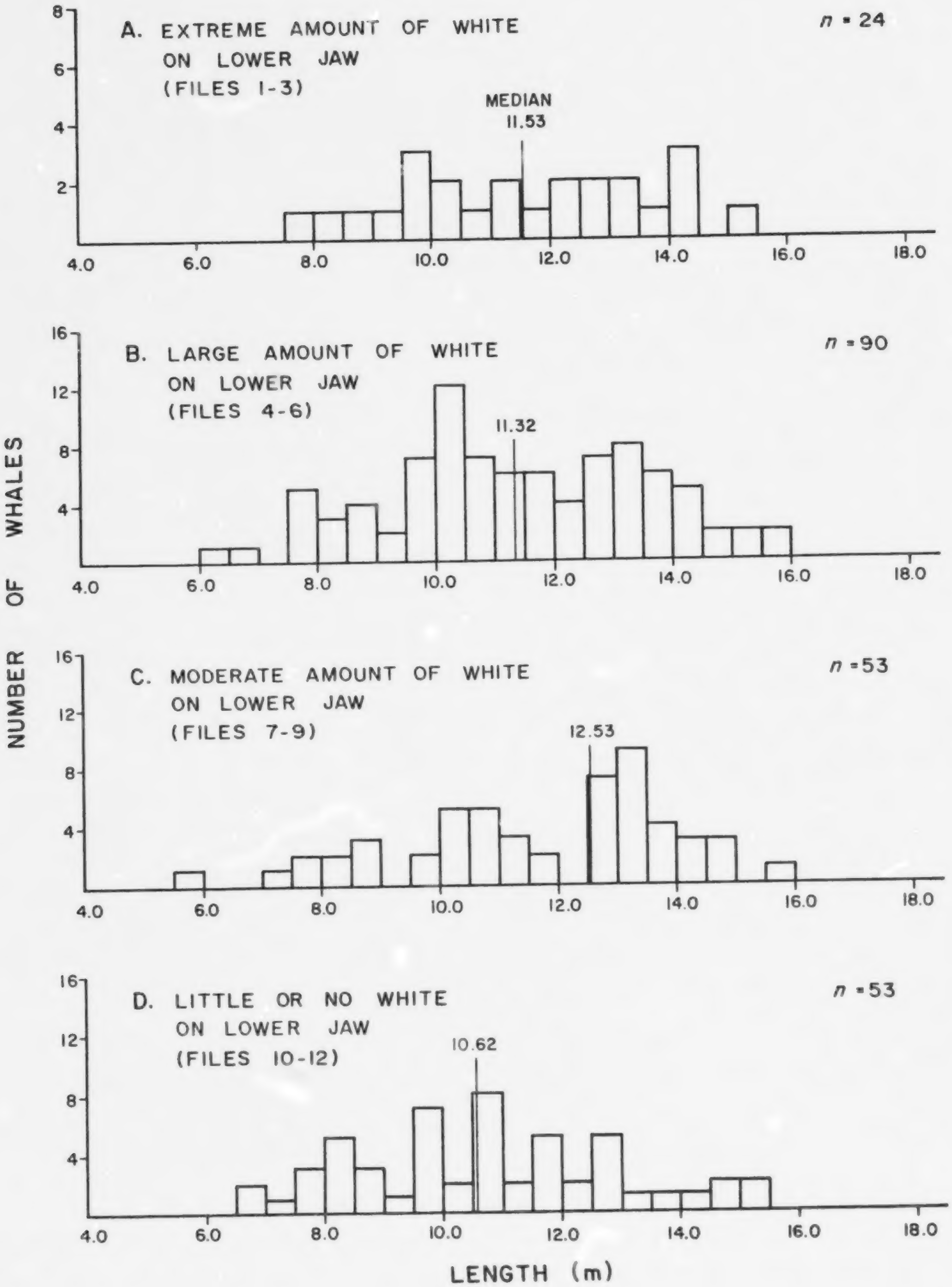


FIG. 36. Length-frequency distributions (repeated photos excluded) of bowhead whales classified according to the amount of white pigmentation on the lower jaw, 1984. (File numbers refer to categories in our photo catalogue.)

Table 26. The amount of white on the lower jaw of bowhead whales as a function of the length of the whale, 1984. Repeated photos are excluded.

Amount of White	Length Categories (m)					All Lengths
	≤10*	10-11	11-12	12-13	>13*	
Extreme	7	3	3	4	7	24
Large	23	19	12	11	25	90
Moderate	11	10	5	7	20	53
Little or None	22	10	7	7	7	53
All Cases	63	42	27	29	59	220

* See Figure 36 for distributions of lengths within these categories.

as compared with 31% in the other three categories combined (Table 26). This difference is statistically significant ($\chi^2 = 6.59$, df = 1, $P<0.01$).

Fluke/Caudal Region

The differences in the length distributions of whales relative to the three categories of white in the fluke/caudal region (Fig. 37) were striking ($\chi^2 = 74.32$, df = 4, $P<0.001$; Table 27). The median lengths of whales ranged from 13.6 m in the category with the most white in the fluke/caudal region to 10.3 m in the category with no white in the fluke/caudal region. The relative proportions of adults (>13 m) and immatures also differed significantly among the three categories ($\chi^2 = 67.12$, df = 2, $P<0.001$).

There were significantly fewer adult whales in the category with no white in the fluke/caudal region than in the categories with extreme ($\chi^2 = 54.07$, df = 1, $P<0.001$) and moderate ($\chi^2 = 39.33$, df = 1, $P<0.001$) amounts of white in the fluke/caudal region. The relative proportions of adults and immatures did not differ between the extreme and moderate categories. Overall, the proportion of adults were 71.4% in the category with extreme white in the fluke/caudal region, 52.0% (moderate white), and only 9.2% in

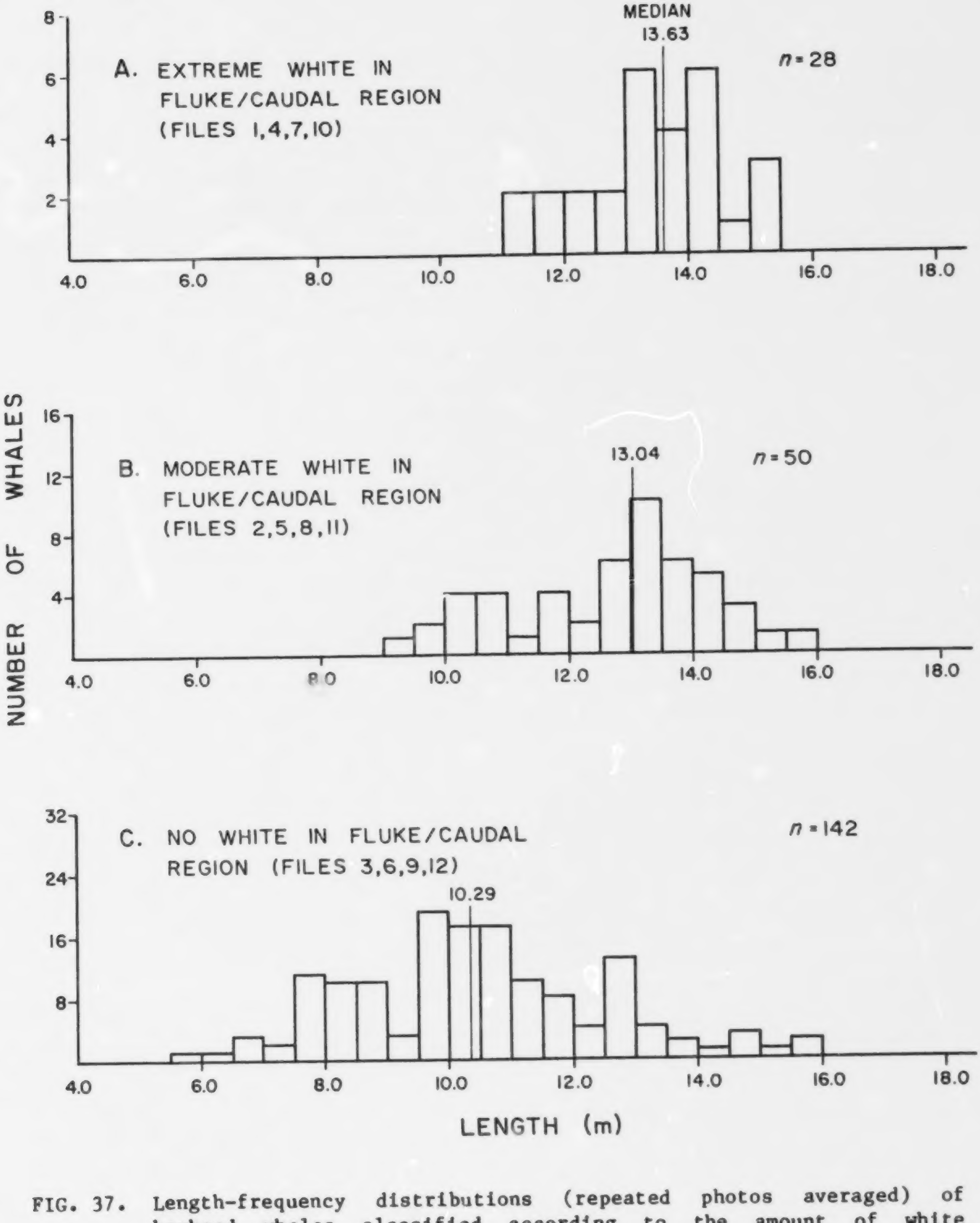


FIG. 37. Length-frequency distributions (repeated photos averaged) of bowhead whales classified according to the amount of white pigmentation in the fluke/caudal region, 1984. (File numbers refer to categories in our photo catalogue.)

Table 27. The amount of white in the fluke/caudal region of bowhead whales as a function of the length of the whale, 1984. Repeated photos are excluded.

Amount of White	Length Categories (m)			All Lengths
	≤12*	12-13	>13*	
Extreme	4	4	20	28
Moderate	16	8	26	50
None	112	17	13	142
All Cases	132	29	59	220

* See Figure 37 for distributions of lengths within these categories.

the category with no white in the fluke/caudal region. These results are similar to our findings in 1982 when the corresponding figures were 86.4, 67.6 and 14.4% in a sample of 291 animals (Davis et al. 1983).

Scarring as a Function of Whale Length

Two types of markings play a fundamental role in the long term (inter-year) re-identification of bowheads. Natural pigmentation markings on the lower jaw and in the fluke/caudal region can be very distinctive and can provide important clues in the recognition of individual bowheads. Scars also provide important and often conclusive aids to the recognition of individual whales. In the following section we analyze scarring as a function of the length of bowhead whales.

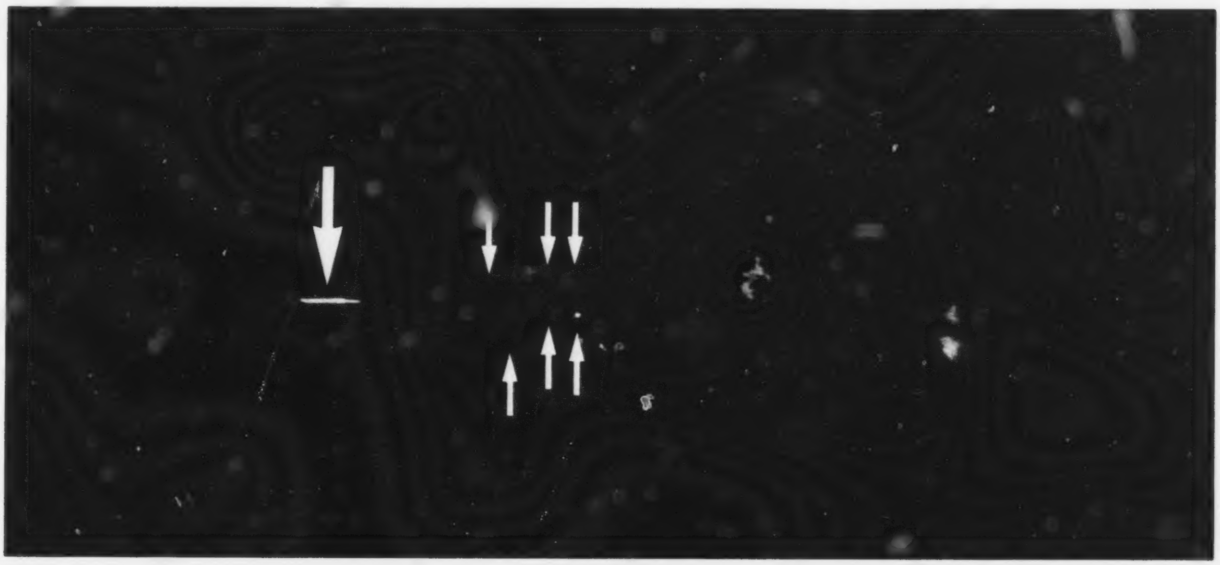
In order to conduct the analysis, we selected photographs of 10 whales in each of 10 one-m length categories, from 6.01-7.00 m to 15.01-16.00 m. In selecting photographs we looked only at measured (grades 1-6) whales in which we had a relatively clear view of the head, back and flukes. We selected whale images in the order they were photographed. In order to obtain a sample of 10 whales in each of the 10 length categories, the 6.01-7.00 and 15.01-16.00 m categories were supplemented by five and one photos, respectively, from our 1982 collection.

The scars visible on each whale were counted and categorized as major, moderate and minor scars, depending on their size and prominence. Major scars are bold, very prominent linear scars, usually at least 1-2 m in length. Moderate scars are smaller, bold and prominent scars of irregular shapes. Minor scars are small less prominent markings. Plate 3 shows examples of the three scar categories. In some cases it was difficult to determine whether the minor, and sometimes moderate, markings apparent in the photograph were scars, or merely highlights, reflections or wash. When more than one photograph of a particular whale was available they were carefully compared to eliminate spurious scars. When no repeats were available we used our best judgement in an attempt to determine which apparent markings were actual scars.

We weighted the three scar categories in the following manner: a major scar was awarded twice the weight of a moderate scar, which was awarded five time the weight of a minor scar. Thus, in computing a scarring index a major scar was worth 10 points, a moderate scar five points, and a minor scar one point. This weighting system is arbitrary but is based on our subjective evaluation of the increased potential for recognition that the various types of scars afford a particular whale image. For example, we believe that a whale with five minor scars is approximately as recognizable as a whale with a single moderate scar, and about half as recognizable as a whale with a major scar. A scar index value was determined for each whale according to the formula

$$\text{Scar Index Value} = 10\,[\text{number of major scars}] + 5\,[\text{number of moderate scars}] + \text{number of minor scars}.$$

Thus, a whale with a single major scar, 2 moderate scars and 14 minor scars would have scar index value of $10(1) + 5(2) + 14 = 34$. The mean scar index value for each of the various length categories was determined by taking the average of the individual scar index values in that length category. The mean scar index value for each of the 10 length categories is plotted in Figure 38. The scar index values clearly increase with length, but this increase does not appear to be linear. The number of scars is relatively



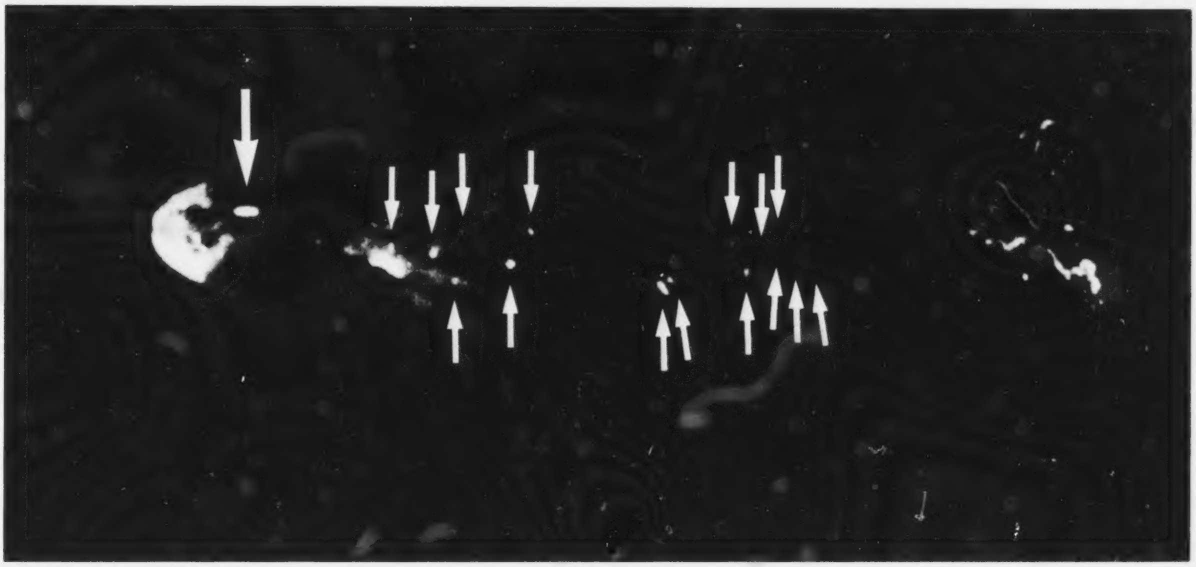


Plate 3. Examples of major, moderate and minor scars on bowhead whales photographed in the Canadian Beaufort Sea during August and September 1984. Photograph 84-15-13 (upper), taken on 22 August in the North Industrial Zone, shows a 14.56 m (measurement grade 4) bowhead with one major and six minor scars. The scar index for this individual is 16. Photograph 84-46-09 (lower), from the North Industrial Zone on 2 September, shows a 15.67 m (measurement grade 1) bowhead with one moderate and at least 15 minor scars. The fact that additional scars may be present in the fluke/caudal region precludes the determination of a scar index for this whale, but based on the parts of the whale that are clearly visible the scar index is at least 20. (See text for explanation of how scar index values were calculated.)

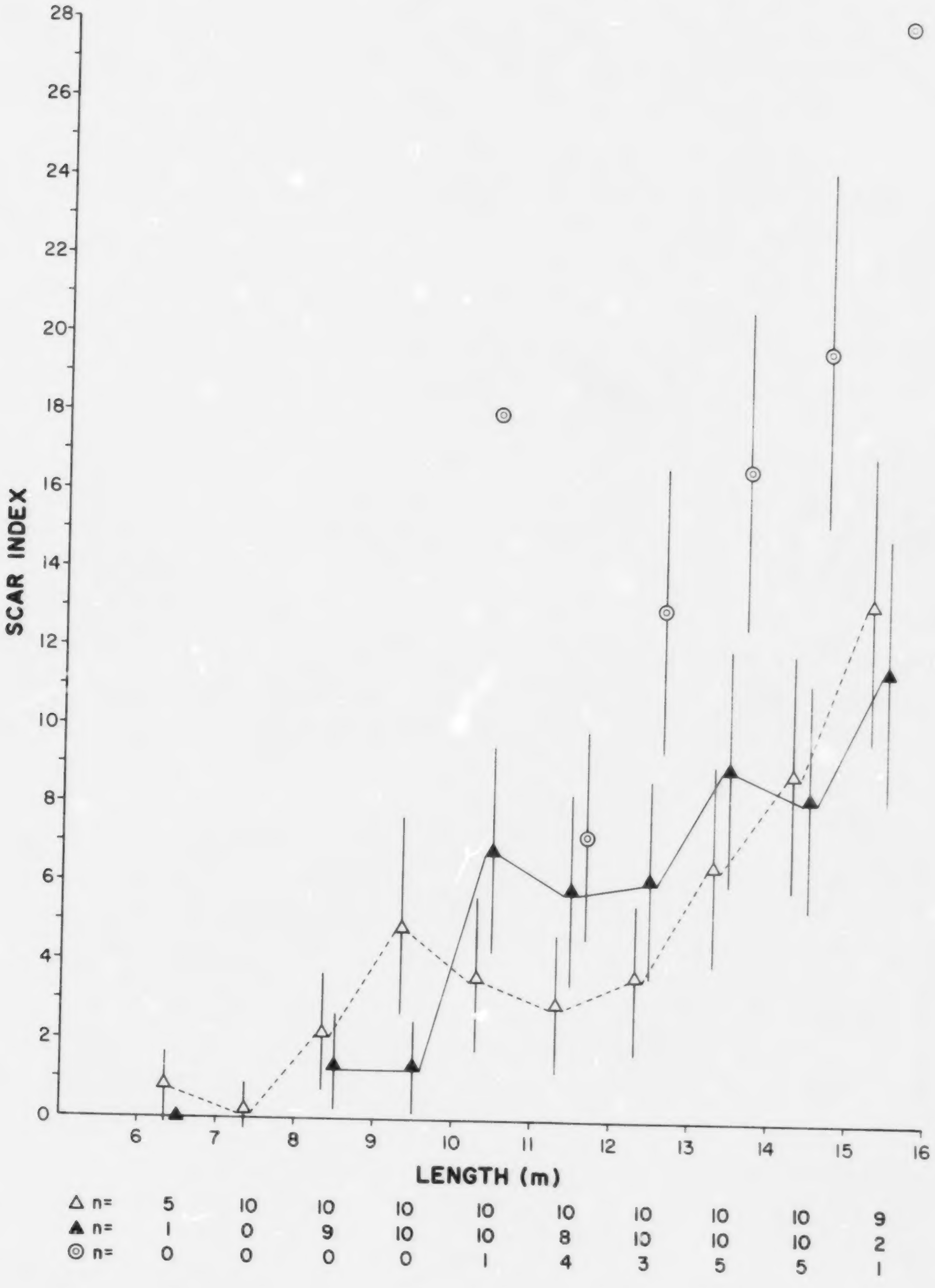


FIG. 38. Scar index values (mean and standard deviation) for the 1984 general sample (△), 1984 within-day duplicates (▲), and 1982 and 1984 inter-day and inter-year duplicates (◎).

higher for whales over 13 m in length. This would be expected if scar acquisition is a function of whale age rather than whale length.

We also determined scar index values for whales that were photographed more than once during the 1984 study. Since it should be easier to recognize repeated photographs of heavily scarred whales, one might hypothesize that recognized repeats, as a sub-sample of our 1984 whale images, should be particularly heavily scarred and therefore have an unusually high scar index. We determined scar index values of whales photographed more than once on the same day for a maximum of 10 whales in each of eight 1 m length intervals from 8-9 m to 15-16 m. The mean scar index values for these length categories are plotted in Figure 38. The mean scar index values for repeats averaged slightly higher than the scar index values for 1984 whales in general. The mean scar index value for repeats (based on the average of the mean scar index values of the eight 1 m length categories) was 6.3 vs. 5.8 for the general sample. This difference is equivalent to an average difference of 1/2 of a minor scar per whale and is probably trivial. This leads to the conclusion that recognized repeat whale images are not much more heavily scarred than our 1984 sample in general. If recognized repeat images are more recognizable, it is probably due primarily to mottling patterns and/or pigmentation patterns on the lower jaw and fluke/caudal regions rather than scars.

We also compared the scar index values of inter-day and inter-year repeats with the scar index values in the general 1984 sample. To increase the size of the inter-day/year sample we included 1982 photos. Inter-day/year repeats were available for six 1 m length intervals from 10-11 to 15-16 m. The mean scar index values for the six length intervals are plotted in Figure 38. These values averaged much higher than the corresponding values for the 1984 sample in general. The average of the mean scar index values determined for the six length intervals was 17.1 vs. 6.5 for the general 1984 sample.

The difference in these values (10.6) is equivalent to one major scar, two moderate scars or more than 10 minor scars, suggesting that recognized inter-day/year repeats are much more heavily scarred than the general 1984 sample. The average length of the 20 inter-day/year repeats was 13.0 m. The actual average scar index value of these 20 whales was 14.8, much higher than the general 1984 scarring index for this length interval (6.5) and higher than the value (13.3) determined for the most heavily scarred general length category (15-16 m). Thus, while non-scar markings (mottling and lower jaw and fluke/caudal markings) appear to be important factors in the recognition of whales photographed more than once on the same day, scarring is apparently very important in the recognition of inter-day/year repeats. Scarring increases with whale length, so inter-day/year repeats are usually large whales, or extraordinarily heavily scarred small whales.

Re-identification vs. Whale Pigmentation Patterns

It is of interest to determine whether certain pigmentation patterns on bowheads are more important in individual recognition than are other patterns. Overall, there are 219 prints representing 83 different re-identified whales in files 1-12 of our photographic catalogue for 1984. Photographs of 53 other re-identified whales are of insufficient quality to determine all the natural markings on them (see Methods) and these prints are not considered in the present analysis. On average, the 83 individuals were photographed 2.64 times. Five of the 83 whales were photographed on more than one day; the remaining 78 were re-photographed on the same day that they were originally photographed.

The proportion of the whales that were re-identified differed significantly among jaw color categories ($\chi^2 = 10.23$, df = 3, $P<0.02$). The percentages of whales re-identified ranged from 62.5% (15 of 24) for whales with "extreme" amounts of white on the lower jaw to 27.0% (17 of 63) for whales with "little or no" white on the lower jaw (Table 28). In contrast, the proportion of the whales that were re-identified did not differ significantly among fluke/caudal categories ($\chi^2 = 4.01$, df = 2, $P>0.10$). In our 1982 sample (Davis et al. 1983), we found the opposite trend; the proportion of whales that were re-identified differed significantly with the amount of white in the fluke/caudal region, but not with the amount of white on the lower jaw. Cubbage et al. (1984) found that ability to recognize "non-links" (definite non-repeats) in their 1983 sample was in part a function of the amount of white on the lower jaw.

Table 28. Pigmentation patterns of re-identified and not re-identified bowhead whales, 1984.

Amount of White on Lower Jaw	Amount of White in Fluke/Caudal Region							
	Extreme		Moderate		None		Total	
	Number of individuals		Number of individuals		Number of individuals		Number of individuals	
	Re-identified	Not Re-identified	Re-identified	Not Re-identified	Re-identified	Not Re-identified	Re-identified	Not Re-identified
Extreme	5	0	4	4	6	5	15	9
Large	6	9	5	10	20	47	31	66
Moderate	2	1	9	10	9	24	20	35
Small	2	5	2	11	13	30	17	46
Totals	15	15	20	35	48	106	83	156

Unrecognized Repeated Photos

In the previous section we showed that whales with "extreme" amounts of white on the lower jaw were the most recognizable individuals; 46.7% (21 of 45) of these whale images were repeat photographs of previously identified individuals. Since this category contains the most recognizable individuals, it is reasonable to assume that the percentage of repeats found in this category (46.7%) is the best estimate of the percentage of actual repeats in the entire sample.

We identified 36.3% (136 of 375) of the images in files 1-12 as repeats. If we assume that 46.7% (175 of 375) were actually repeats, then we recognized only 77.7% (136 of 175) of the repeats theoretically present. Thus, we missed 39 hypothetical repeats, 18 of which should have been whales with a "large" amount of white on the lower jaw, eight of which should have had a "moderate" amount of white on the lower jaw, and 13 of which should have had "little or no" white on the lower jaw.

We can use a similar approach to estimate the number of unrecognized repeats present in the length-frequency histograms shown in Figure 35. For this analysis we are interested in estimating the number of measured repeats present in our photo catalogue. We found that 31.4% (11 of 35) of the measured whales with "extreme" amounts of white on the lower jaw were repeat photographs. The comparative figures for whales with "large", "moderate" and "little or no" white on the lower jaw were 27.4% (34 of 124), 25.7% (18 of 70) and 24.6% (17 of 69), respectively. If we assume that the percentage (31.4) observed for whales with "extreme" amounts of white on the lower jaw is the best estimate of the actual number of measured repeats in our sample (n = 298), then we can calculate the number of measured repeats that we were unable to recognize. There should be a total of 94 (0.314 x 298) repeats in our sample of 298 measured whales. We found 80 of these repeats and failed to recognize 14. Five of these unrecognized repeats should be whales with "large" amounts of white on the lower jaw, four should have "moderate" amounts of white, and five should have "little or no" white on the lower jaw.

If the above assumptions are correct then our sample of measured prints contains 4.7% (14 of 298) unrecognized repeats. Assuming that those missed prints occur in the same length proportion as do the prints in the "large", "moderate" and "little or no" white lower jaw categories then it is possible to estimate the lengths of the missed repeats. The distribution of prints for which length measurements are available is given in Table 29. The five unrecognized repeat images in the "large" category would include 3.3 prints in the ≤13 m interval and 1.7 prints over 13 m. The four unrecognized repeats in the "moderate" lower jaw category would include 2.5 prints in the ≤13 m interval and 1.5 prints over 13 m. The five missed repeats in the "little or no" white lower jaw category would include 4.3 prints ≤13 m and 0.7 prints over 13 m.

Table 29. Length distribution of whale images as a function of the amount of white on the lower jaw, 1984.

Amount of White on Lower Jaw	Length Category ≤13 m	Length Category >13 m	All Lengths
Extreme	24	11	35
Large	83	41	124
Moderate	44	26	70
Little or None	60	9	69
All Cases	211	87	298

Frequency of Re-identifications

In an earlier section we demonstrated that the percentages of re-identified whales in our sample differed significantly among files with regard to the amount of white pigmentation on the lower jaw but not in the fluke/caudal region. In the following analysis we examine the number of recognized repeat photographs per re-identified whales as a function of lower jaw and fluke/caudal categories and length.

Overall, 213 measurements were obtained of the 80 different re-identified whales for which full pigmentation data were available (Table 30). On average, each of these whale was re-photographed 2.66 times. There was a slight tendency for the larger adult (>13 m) whales to be re-identified more often (2.87 times) than the smaller whales (2.54 times--Table 30). However, within each size category there was no clearcut trend toward animals with more white on the lower jaw being re-identified more often than less well-marked animals. Thus, there is a mild tendency for larger whales to be re-identified more often but this trend is not a function of the amount of white on the lower jaw.

Table 30. Number of photographs per re-identified individual as a function of lower jaw markings and whale length, 1984.*

Amount of White	Length Category		All Lengths
	≤13 m	>13 m	
Extreme	2.56 (9)**	2.17 (6)	2.40 (15)
Large	2.32 (19)	3.27 (11)	2.67 (30)
Moderate	2.36 (11)	3.00 (9)	2.65 (20)
Little or None	3.09 (11)	2.50 (4)	2.93 (15)
All Cases	2.54 (50)	2.87 (30)	2.66 (80)

* Includes only whales for which all markings could be fully categorized (i.e. files 1-12). Lengths of three re-identified whales were unavailable.

** Sample size.

The number of photographs per re-identified whale are shown as a function of the amount of white in the fluke/caudal region in Table 31. When the two length categories are combined, the average number of photographs/ re-identified whale decreases slightly from 2.80 for whales with "extreme" amounts of white in the fluke/caudal region to 2.63 for whales with no white in the fluke/caudal region (Table 31). When the three fluke/caudal categories were combined, the average number of photographs/re-identified whale was higher for whales >13 m (2.87) than for whales ≤13 m (2.54). In 1982 Davis et al. (1983) found that the average number of photographs/re-identified whale decreased with decreasing white in the fluke/caudal region. However, in 1982 the average number of photographs/re-identified whale was independent of length, whereas in the 1984 sample, large (>13 m) re-identified whales were re-photographed slightly more frequently than smaller (≤13 m) whales.

Table 31. Number of photographs per re-identified individual as a function of fluke/caudal markings and whale length*.

Amount of White	Length Category		All Lengths
	≤13 m	>13 m	
Extreme	2.00 (2)**	2.96 (13)	2.80 (15)
Moderate	2.60 (5)	2.69 (13)	2.67 (18)
None	3.56 (43)	3.25 (4)	2.62 (47)
All Cases	2.54 (50)	2.87 (30)	2.66 (80)

* Includes only whales for which all markings could be fully categorized (i.e. files 1-12). Lengths of three re-identified whales were unavailable.

** Sample size.

Future Re-Identification

We assigned re-identification grades to each of the 375 prints in files 1-12 of our 1984 photograph catalog. The photographs in these files are those that could be fully classified with respect to pigmentation patterns on the lower jaw and fluke/caudal region. All prints in files 1-12 were considered A or B grade prints. Photographs of re-identification grade A represent whales that we believe can be re-identified in future years. Grade A prints represented 41.3% (155 of 375) of the photographs in files 1-12.

Grade A prints comprised 80.7% (46 of 57) of the total prints in the fluke/caudal category with extreme amounts of white, 50.6% (44 of 87) in the category with little white, and 28.1% (65 of 231) in the category with no white ($\chi^2 = 56.08$, df = 2, $P<0.001$). The percentages of grade A prints in the four lower jaw categories ranged from 55.6% (25 of 45) in the category with most white to 34.0% (32 of 94) in the category with the least white, but the observed differences were not significant ($\chi^2 = 5.98$, df = 3, $P>0.10$).

The total of 155 grade A photographs among the 375 fully classified prints includes repeated photos. A maximum of 114 different whales were represented in the grade A photos. This is 47.7% of the 239 individuals represented among the 375 prints. An additional 76 prints among the 571 prints in files 13-20 (containing incompletely classified animals) represented 72 additional re-identifiable (grade A) individuals. Thus, among the 1114 whale images obtained in the study, there were 186 (16.7%) individuals that are considered to be re-identifiable in the future.

This estimate (186 different individuals) should be considered speculative until it is possible to examine additional photographs of the same whale taken in different years.

DATA APPENDIX 1

Table 32. Lengths and measurement grades of re-identified whales.

Photo Number	Length (m)	Measurement Grade	Resighting									
			First		Second		Third		Fourth		Fifth	
			Length (m)	Measure. Grade	Length (m)	Measure. Grade	Length (m)	Measure. Grade	Length (m)	Measure. Grade	Length (m)	Measure. Grade
84-03-11	–*	–*	–	–								
84-03-12	12.26	7	12.19	7								
84-03-17	–	–	11.01	7								
84-04-07	8.26	3	–	–								
84-04-08	–	–	9.43	4								
84-04-11	10.46	2	10.42	2								
84-04-17	–	–	8.61	SB-3								
84-06-06	12.97	2	12.70	3								
84-06-07	10.68	3	–	–								
84-06-08	11.00	1	11.20	2								
84-06-13	9.99	2	9.82	3								
84-06-14	12.39	2	12.69	1								
84-06-15	11.39	3	11.00	3								
84-06-17	12.91	1	12.68	1								
84-06-18	9.52	3	9.57	4								
84-08-04	9.83	5	9.98	2	9.92	2						
84-08-05	11.71	5	11.39	7								
84-08-10	10.05	2	9.88	4	9.89	2						
84-09-04	9.99	6	–	–	–	–						
84-09-05	–	–	9.63	SB-2								
84-09-11#1	–	–	10.30	4								
84-09-14#1	8.62	4	–	–	8.72	4	8.47	4				
84-09-18	11.83	6	–	–								
84-09-19	14.00	4	13.96	1	–	–						
84-10-01	12.08	4	12.47	3								
84-10-17	8.68	5	8.75	4								
84-11-09	10.65	2	–	–								
84-11-16	10.19	3	8.75	7	10.12	3						
84-11-17#1	9.86	7	10.32	3								
84-12-16	8.66	3	9.16	6								
84-12-18	10.65	3	–	–								
84-12-20#1	10.29	5	10.24	4	10.00	4						
84-13-04	10.32	3	11.13	SB-2	–	–						
84-15-20	–	–	10.83	5	–	–						
84-16-16	9.39	FW-4	–	–								
84-17-02	–	–	11.12	6								
84-17-05	7.69	SB-4	–	–	13.21	4	12.67	4	13.35	3		
84-18-05	13.21	1	13.44	6								
84-18-13	11.91	4	11.76	4								
84-18-14	–	–	–	–								
84-18-21	14.15	6	14.02	4								

Continued...

Table 32. Continued.

			Resighting									
			First		Second		Third		Fourth		Fifth	
Photo Number	Length (m)	Measurement Grade	Length (m)	Measure. Grade	Length (m)	Measure. Grade	Length (m)	Measure. Grade	Length (m)	Measure. Grade	Length (m)	Measure. Grade
84-19-08	11.69	SB-3	11.25	5								
84-19-09#1	13.43	4	13.59	5								
84-19-09#2	15.51	SB-3	15.37	2								
84-19-16	12.94	4	13.25	2								
84-20-02	15.05	SB-2	14.88	5								
84-20-05#1	12.18	4	-	-								
84-20-05#2	-	-	-	-	12.24	4						
84-20-18	13.81	1	13.92	4	13.98	3						
84-20-21	13.84	3	13.62	4								
84-21-01	11.20	3	12.88	FW-3								
84-22-06	10.73	SB-2	-	-								
84-22-15	9.75	6	-	-								
84-24-03	-	-	9.46	5								
84-25-12	-	-	-	-	-	-	-	-				
84-25-18	-	-	-	-								
84-25-19	-	-	-	-								
84-27-12	12.39	SB-2	-	-								
84-27-14	12.83	SB-3	13.34	SB-3	12.00	3						
84-27-19#1	8.30	6	8.40	6								
84-27-19#2	9.15	6	9.04	3								
84-30-09	-	-	-	-	11.79	4	11.84	4	11.61	3	11.79	5
84-30-18#1	8.40	4	-	-								
84-30-18#2	-	-	-	-								
84-31-01	11.35	6	13.12	SB-3								
84-31-02#1	6.71	4	6.41	4								
84-31-02#2	14.51	3	13.92	6								
84-31-07	9.67	SB-3	10.37	6								
84-33-02	10.76	6	10.77	4								
84-33-06	10.72	SB-3	10.35	4								
84-34-19	10.22	6	-	-	9.87	4						
84-34-20#1	8.67	SB-4	-	-								
84-35-16	10.05	4	-	-								
84-35-19	11.54	6	11.02	4								
84-35-21#4	7.67	4	8.33	4								
84-36-03	9.76	6	10.29	4								
84-36-15	14.23	4	14.15	3								
84-36-18	12.81	4	12.46	6	-	-						
84-36-19#1	-	-	13.64	6	13.55	6	-	-	-	-		
84-36-19#2	13.88	6	13.46	4	13.92	4	13.62	6	13.13	4		
84-37-17	14.10	6	13.97	6								

Continued...

Table 32. Continued.

Photo Number	Length (m)	Measurement Grade	Resighting									
			First		Second		Third		Fourth		Fifth	
			Length (m)	Measure. Grade	Length (m)	Measure. Grade	Length (m)	Measure. Grade	Length (m)	Measure. Grade	Length (m)	Measure. Grade
84-37-21	13.06	6	13.30	6								
84-38-01	14.40	3	14.60	5	14.43	3						
84-38-03	-	-	13.35	4								
84-38-08	13.41	3	-	-	13.44	4						
84-38-09	-	-	14.84	4								
84-38-13	12.21	6	-	-								
84-38-17	14.20	6	13.91	4	13.34	SB-3						
84-39-17	12.75	4	12.64	2	12.62	3						
84-40-18	11.50	6	11.33	7								
84-40-19#1	10.16	6	-	-								
84-40-19#2	9.93	6	9.96	6	10.22	4						
84-41-05	-	-	-	-								
84-42-13#2	9.38	4	-	-	11.32	SB-4	-	-				
84-42-14#3	8.51	2	9.11	6								
84-42-21	-	-	-	-								
84-44-03#1	12.65	2	9.66	7	14.32	FW-2	12.16	5				
84-44-03#2	14.26	1	12.93	7	14.38	2	14.88	6	14.54	6		
84-44-03#3	12.61	4	11.64	7								
84-44-03#4	13.96	2	11.13	7	13.82	1	13.85	7	14.39	5	13.69	3
84-44-06	12.85	1	12.71	2	12.81	5						
84-44-08	13.30	2	13.09	5	12.67	2						
84-44-10#1	9.24	4	9.06	3								
84-44-10#2	13.78	1	14.36	3								
84-44-11#2	15.09	2	15.22	3								
84-44-11#3	12.81	2	13.54	5	13.11	3	12.84	7				
84-44-11#4	13.97	3	15.29	6								
84-44-12#4	12.33	4	12.43	3								
84-44-13#1	15.01	3	14.23	7	14.63	4	-	-	14.56	3		
84-44-13#2	-	-	12.81	7	13.53	2	13.97	3				
84-44-13#3	9.94	4	9.62	7	9.86	2	10.26	2	9.60	6		
84-44-16#2	13.49	6	13.09	4								
84-44-18	14.10	3	13.73	FW-4	13.85	2						
84-45-10#1	-	-	6.66	7	6.61	3						
84-45-12	10.94	7	-	-	12.31	SB-4						
84-45-18	-	-	13.01	5								
84-45-19	-	-	6.39	4	6.12	7						
84-45-21	-	-	14.23	4								
84-48-05	-	-	13.84	4								
84-48-12	-	-	14.50	SB-6								
84-50-06	-	-	-	-								

Continued...

Table 32. Concluded.

Photo Number	Length (m)	Measurement Grade	Resighting									
			First		Second		Third		Fourth		Fifth	
			Length (m)	Measure. Grade	Length (m)	Measure. Grade	Length (m)	Measure. Grade	Length (m)	Measure. Grade	Length (m)	Measure. Grade
84-50-17	-	-	-	-								
84-51-11	10.43	3	11.28	4								
84-51-15	-	-	11.31	SB-6								
84-51-17	12.64	4	12.96	6								
84-52-02	9.55	3	9.68	2								
84-54-08#2	-	-	9.48	7								
84-57-06	-	-	-	-	-	-						
84-58-10	8.38	5	7.72	5								
84-62-08	9.60	5	-	-	9.93	4	9.36	3				
84-62-09#1	9.47	5	9.07	5								
84-62-09#2	9.86	6	9.31	5	9.51	FW-6	9.76	3				
84-63-03	-	-	9.14	6	-	-						
84-63-07	9.00	4	8.79	6								
84-63-10	8.56	5	-	-								
84-64-07	-	-	-	-								
84-64-10	-	-	-	-								

* Whale identified but could not be measured.